Beyond Frameworks of Fidelity: Tracking Collaborative Design to Promote Multiple Perspectives of Science in the Classroom

by

Jeffrey L. Spencer

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy (Chemistry) in the University of Michigan 2022

Doctoral Committee:

Professor Ginger V. Shultz, Chair
Professor Brian P. Coppola
Professor Anne R. Gere
Professor Vilma M. Mesa
Dedication

To my father, who would have delighted in this moment; to my sons, who inspire my work.
Acknowledgements

The completion of this dissertation connects to a long lineage of strong women in my life. I am overwhelmingly grateful to my partner, Hannah Spencer, for her openness to adventure, willingness to uproot our family, and continual support for me and my sons throughout my graduate work. She is my foundation, and none of this would be possible without her. I am also thankful for my mother, Shelley Godwin, and two sisters, Elise and Lauren Spencer, who demonstrated how to break down societal norms from a young age. The strength of my mother-in-law, Marcella Whittaker, is apparent not only in the strength of her children, but also in her ability to provide sound guidance while always being in your corner. Professor Ginger Shultz showed me that my ideas were worth pursuing and helped me gain the confidence and perspective to stand up for what is important. Her ability to listen, respond, and advocate is moving mountains, and I am regularly grateful for her role in my professional life. My growth as an early researcher is attributed to Leah Bricker, who gave me tools to challenge post-positivistic perspectives, showed me how to advocate for others in my work, and connected me to worlds beyond my community. Committee members Professor Vilma Mesa and Professor Anne Gere offered challenging feedback and support that developed this work as well as my own identity, both having paved a road for young scholars to pursue justice-oriented academic work that was considered impossible until recently. Danielle Maxwell was my partner-in-crime, sharing the emotional roller-coaster that is collaborative design and offering words of encouragement through the process. Her wisdom and strength are beyond her years. Professor Kathryn Hosbein and Professor Paulette Vincent-Ruz refined my writing, perspectives, and identity as they confronted perspectives of inequity in Chemistry Education, and I am thankful for their friendship. May my sons know, respect, and promote strong feminine perspectives as they grow.

My previous experiences as a teacher inform my work. I am grateful for Dr. Don Decoste and Dr. Gretchen Adams for modeling the importance of great teaching, affirming my own decision to become a teacher, and mentoring me throughout my career. The staff at Vista Peak Preparatory in Aurora, CO during my early career, including Katie Law-Balding, Jason LePera, Christopher Moros, Hannah Aslin, Jeff Cramer, and numerous others, embody the grit, empathy,
and talent that is necessary to be a successful secondary educator. I am truly honored to have you as colleagues. The students at Vista Peak taught me more than I ever can reciprocate, growing my understanding of the necessity of multiple perspectives through first-hand experience. I am forever marked by your resilience, creativity, and generosity. The Knowles Teacher Initiative transformed my perspective on how to be a teacher-leader, supporting my growth through practitioner inquiry and professionalism. The 2011 cohort will always be my professional family, and I am excited to continue growing with them in the decades to come. Professor Erin Furtak and her graduate students (at the time), Dr. Jason Buell and Dr. Caitlin Fine, showed me the importance of teacher voice in greater education research, supporting me as I considered research. The collective experiences with my students and practitioner colleagues grounds my perspective, putting faces, communities, and structures to the implications of my work.

My trajectory and growth as a researcher are due to the expertise of the community that surrounds me. Committee member Professor Brian Coppola continues to refine my perspective on the implications of research as it relates to teaching practice, providing solace that there exist infinite outcomes for people who think critically about most situations. Professor Barry Fishman provided mentorship and valuable experience as I learned about designing and studying the effects of learning environments. I appreciate the Shultz group for providing a safe environment to help me find narratives in the complexity of design work. Joshua Kenney and J.J. Mayers kept me grounded through extended chats over coffee about theories and frameworks and their relation to actual classrooms. I am grateful for the School of Education, including Professors Betsy Davis and Leslie Herrenkohl, for sharing their resources, knowledge, and feedback as I grew as a researcher. Jared Ten Brink, Saba Gerami, Michael Ion, Michole Washington, and Darrius Robinson were wonderful critical friends at various points as I explored the intersection of my research, identity, and culture.

Finally, I will forever be shaped by the community of Utqiaġvik, Ilisaġvik College, the Elders who interacted in the classroom, and the student participants of my research for their warm hospitality, willingness to show the strength of their culture, and resilience as they work to reclaim their culture. Kaare Sikuaq Erickson and Jericha Aamodt were skilled guides as we learned about the social, political, and cultural context of the North Slope. I am also grateful for Professors Linda Nicholas-Figueroa, Daniel Wall, and Kerri Pratt for their guidance during our collaboration.
Table of Contents

Dedication ................................................................................................................................. ii
Acknowledgements .................................................................................................................... iii
List of Tables .............................................................................................................................. xii
List of Figures ............................................................................................................................ xiv
Abstract ..................................................................................................................................... xvi

Chapter 1 Crossroads of Epistemology in the Classroom: A Case for Collaborative Design of Science Instructional Materials ...................................................................................... 1

1.1 Abstract .............................................................................................................................. 1

1.2 Introduction ......................................................................................................................... 1

1.3 Knowledge Construction in Science .................................................................................... 3

1.3.1 Disciplinary Perspective of Epistemology ................................................................. 4
1.3.2 Personal Perspective of Epistemology ........................................................................ 4
1.3.3 Practical Perspective of Epistemology ........................................................................ 5
1.3.4 Scientific Epistemology in Relation to the NGSS Science and Engineering Practices . 6
1.3.5 Cultural Perspectives of Science .................................................................................. 7
1.3.6 Examples of Multiple Representations of Epistemology ............................................. 8

1.4 Design and Implementation Methodologies ........................................................................ 9

1.4.1 Fidelity of Implementation and Adaptation ............................................................... 9
1.4.2 Positionality of the Designer ...................................................................................... 11
1.4.3 Collaborative Design ................................................................................................. 11
# Chapter 2 Moderating Variables and Fidelity of Implementation: The Use of Teacher Sensemaking to Guide Adaptive Curriculum Design

## 2.1 Initial Remarks

## 2.2 Abstract

## 2.3 Introduction

### 2.3.1 Fidelity of Implementation Framework

### 2.3.2 Research Questions

## 2.4 Methods

### 2.4.1 Research Context

### 2.4.2 Identification of Critical Components

### 2.4.3 Participants and Teaching Contexts

### 2.4.4 Workshop Context

### 2.4.5 Data Collection and Sources

### 2.4.6 Data Analysis

### 2.4.7 Validity

## 2.5 Results and Discussion

### 2.5.1 Critical Components – Relevance

### 2.5.2 Critical Components – Science and Engineering Practices

### 2.5.3 Critical Components – Disciplinary Practices

### 2.5.4 Critical Knowledge

### 2.5.5 Critical Knowledge – Students

### 2.5.6 Critical Knowledge – Teacher

### 2.5.7 Negotiation

## 2.6 Implications for the Design Process
2.6.1 Considerations for the FOI Framework ................................................................. 61
2.6.2 Relegating Power ...................................................................................................... 63
2.7 Conclusion .................................................................................................................... 64
2.8 Acknowledgements ..................................................................................................... 64
2.9 Supplemental Materials ............................................................................................. 65
  2.9.1 Expert Consultation ................................................................................................. 65
  2.9.2 Coding Scheme ....................................................................................................... 65
  2.9.3 Initial Deductive Coding: Critical Components ...................................................... 66
  2.9.4 Initial Inductive Coding: Critical Knowledge ......................................................... 67
  2.9.5 Final Coding: Critical Knowledge .......................................................................... 68
  2.9.6 Code Condensation ............................................................................................... 70
  2.9.7 Expansion of Results – Science and Engineering Practices: Asking Questions and
      Defining Problems ........................................................................................................ 71
  2.9.8 Expansion of Results – Critical Component: Disciplinary Practices .................... 72
2.10 References .................................................................................................................. 73

Chapter 3 Scientific Epistemology in the Classroom: How Do Science and Engineering Faculty
Represent the Science and Engineering Practices? ................................................................ 78
  3.1 Initial Remarks ........................................................................................................... 78
  3.2 Abstract ...................................................................................................................... 79
  3.3 Introduction ................................................................................................................ 80
    3.3.1 Scientific Epistemology ...................................................................................... 82
    3.3.2 Disciplinary Perspective of Epistemology .............................................................. 82
    3.3.3 Personal Perspective of Epistemology ................................................................. 83
    3.3.4 Practical Perspective of Epistemology ................................................................. 84
    3.3.5 Disciplinary Learning .......................................................................................... 84
    3.3.6 Structures that Promote Disciplinary Learning ................................................... 86
3.4 Methods .................................................................................................................. 87
3.4.1 Population and Participants ................................................................................ 88
3.4.2 Data Collection ..................................................................................................... 89
3.4.3 Analysis of Data .................................................................................................... 90
3.5 Findings .................................................................................................................. 91
3.5.1 Michael — Mangling of Practices ........................................................................ 91
3.5.2 Lindsay — Communication, Context, and Disciplinary Authority ...................... 98
3.5.3 Byron — Data Analysis, Error, and Systems Thinking ....................................... 101
3.5.4 Eve — Engineering Practices and Human Centered Design .............................. 106
3.6 Conclusions ............................................................................................................ 110
3.6.1 Perspectives of Scientific Epistemology .............................................................. 111
3.6.2 Relationship to the Science and Engineering Practices ..................................... 113
3.6.3 Summary ............................................................................................................ 114
3.7 Acknowledgments .................................................................................................. 115
3.8 Supplemental Material .......................................................................................... 116
3.8.1 Semi-Structured Faculty Interview Protocol ...................................................... 116
3.8.2 Descriptive Cases of Faculty Participants: Michael ........................................... 116
3.8.3 Descriptive Cases of Faculty Participants: Lindsay ............................................. 123
3.8.4 Descriptive Cases of Faculty Participants: Byron ............................................. 130
3.8.5 Descriptive Cases of Faculty Participants: Eve .................................................. 141
3.9 References ............................................................................................................ 151

Chapter 4 Cultural Relevance in Chemistry Education: Snow Chemistry and the Iñupiaq Community ................................................................................................................. 156

4.1 Initial Remarks ....................................................................................................... 156
4.2 Abstract .................................................................................................................. 158
4.3 Introduction ............................................................................................................ 159
4.3.1 Culturally Relevant Education ................................................................. 159
4.3.2 Cultural Relevance in the Arctic ............................................................. 161
4.4 Snow Chemistry Module Design Process .................................................. 163
  4.4.1 Partnering with the Community ............................................................. 163
  4.4.2 Unit Design and Adaptation ................................................................. 165
  4.4.3 Snow Chemistry Unit ........................................................................... 166
4.5 Findings ....................................................................................................... 169
  4.5.1 Connections between Cultural References and Academic Skills and Concepts ...... 169
  4.5.2 Cultural Representation and Critical Reflection ......................................... 171
  4.5.3 Facilitating Students’ Cultural Competence ........................................... 172
  4.5.4 Critique of Discourse of Power .............................................................. 174
4.6 Conclusions .................................................................................................. 175
  4.6.1 Designing for Cultural Relevance .......................................................... 175
  4.6.2 Flexibility as a Design Principle ......................................................... 175
  4.6.3 Focus on Connecting with the Community ........................................... 176
4.7 Acknowledgments ........................................................................................ 177
4.8 References ................................................................................................... 178

Chapter 5 Using Conjecture Mapping to Track the Collaborative Design and Implementation of a Culturally Relevant Chemistry Unit ......................................................................................... 185
5.1 Initial Remarks ............................................................................................. 185
5.2 Abstract ....................................................................................................... 187
5.3 Introduction ................................................................................................... 187
  5.3.1 Collaborative Design Methodologies .................................................... 189
  5.3.2 Conjecture Mapping to Capture Design .............................................. 191
  5.3.3 Research Questions .............................................................................. 193
  5.3.4 Study Context ..................................................................................... 193
5.6.2 Limitations of Conjecture Mapping and Suggestions for Future Research .......... 240
5.6.3 Conclusions ................................................................................................................. 242
5.7 Acknowledgements ........................................................................................................ 243
5.8 References ...................................................................................................................... 244

Chapter 6 Reflective Memo – A Delicate Dance................................................................. 252
6.1 Positions of Power........................................................................................................... 252
   6.1.1 Power between Reform Efforts and Designers ....................................................... 253
   6.1.2 Power between the Community and Designers...................................................... 254
   6.1.3 Power among Design Team Members ................................................................. 255
   6.1.4 Power between the Practitioner and the Rest of the Design Team...................... 257
6.2 Concluding Remarks ...................................................................................................... 259
6.3 References ...................................................................................................................... 260
List of Tables

Table 2.1. List of Science and Engineering Practices and how they relate to the Mohr Method 33
Table 2.2. Workshop participant information. ................................................................. 34
Table 2.3. Reflective journal questions ............................................................................. 39
Table 2.4. Participant focus group questions ................................................................. 40
Table 2.5. Examples of the critical component of relevance. ....................................... 44
Table 2.6. Examples of the critical component of Science and Engineering Practice of Obtaining, Evaluating, and Communicating Information ........................................................................... 46
Table 2.7. Examples of the critical component of disciplinary practices. ................ 49
Table 2.8. Definitions and examples of critical knowledge categories ....................... 52
Table 2.9. Examples of how teachers negotiated their interpretation of the designers’ critical component with their critical knowledge ................................................................. 59
Table 2.10. Example critical component codes from initial deductive coding .......... 67
Table 2.11. Example critical knowledge codes from initial deductive coding ........... 68
Table 2.12. Example space of negotiation codes from final inductive coding .......... 69
Table 3.1. Summary of faculty participant background information ....................... 88
Table 3.2. Summaries presenting important characteristics of each faculty member’s modules 93
Table 3.3. Summaries of how the faculty members’ modules relate to the Science and Engineering Practices .................................................................................................................. 95
Table 5.1. The four tenets of Culturally Relevant Educationas depicted by Aronson and Laughter (2016). ...................................................................................................................... 189
Table 5.2. Descriptions of words used to identify contributions project team members throughout manuscript. .................................................................................................................. 199
Table 5.3. Summary of data collected for each iteration of the project ...................... 199
Table 5.4. Definitions of the design embodiments as they relate to our initial conjecture map 205

Table 5.5. Definitions of the mediating processes as they relate to our initial conjecture map. 206

Table 5.6. Example analysis of the community resources embodiment as they relate to the mediating processes for Iteration 1. 212
List of Figures

Figure 1.1. A summary of the expanded fidelity of implementation framework. .................. 12

Figure 2.1. A summary of the Stains and Vickrey (2017) Fidelity of Implementation framework.
............................................................................................................................................... 29

Figure 2.2. Structure of the workshop and summary of the collected data......................... 36

Figure 2.3. Research design process slide presented to teachers in the workshop. .......... 37

Figure 2.4. Expanded Fidelity of Implementation Framework......................................... 60

Figure 2.5. Thematic Sketch of the critical components after initial deductive coding using the
Stains and Vickrey (2017) framework.................................................................................. 66

Figure 2.6. Thematic Sketch of the critical knowledge after initial inductive coding when
recognizing teachers contributing contextualized information to the critical components. .... 68

Figure 2.7. Thematic sketch of space of negotiation in our final coding process................ 69

Figure 2.8. Whiteboard depicting the results of consensus-activity .................................. 70

Figure 3.1. Summaries of Personal, Disciplinary, and Practical epistemology and how they relate
within the science epistemology framework...................................................................... 85

Figure 4.1. Location of Utqiagvik Alaska........................................................................ 161

Figure 4.2. Overview of the components of the three sections of the snow chemistry unit and an
overview of the application of CRE principles in the context of culturally motivated
environmental research........................................................................................................ 167

Figure 4.3. Summary of resources used by students to inform their research question....... 170

Figure 5.1. Overview of a conjecture map from Sandoval (2014). ................................. 192

Figure 5.2. Geographic location of Utqiagvik in the U.S. state of Alaska....................... 194

Figure 5.3. An outline of the snow chemistry unit.......................................................... 203

Figure 5.4. Initial conjecture map..................................................................................... 204
Figure 5.5. Snow sample collection map made by scientific researcher from previous sample collection trip. ................................................................. 209

Figure 5.6. Analysis conjecture map example ................................................................. 211

Figure 5.7. Conjecture maps for Iteration 1 ..................................................................... 217

Figure 5.8. Student example of reflection on snow chemistry unit as it relates to their life..... 218

Figure 5.9. Example of student reflecting on their experiences with the research scientist..... 218

Figure 5.10. Conjecture maps for Iteration 2 of the snow chemistry unit. ................. 222

Figure 5.11. Two slides from Student 1’s community presentation depicting a physical barrier between Traditional knowledge and Western science........................................... 224

Figure 5.12. Snow chemistry curriculum map used to guide students through project. .... 227

Figure 5.13. Conjecture maps for Iteration 3 .................................................................... 235

Figure 5.14. Snow layering diagram from snow chem guided inquiry activity that student 4 referred to when describing her experiences with snow layers in her everyday life. ............... 235

Figure 5.15. Student 4’s representation of chloride concentration as it relates to snow depth.. 236

Figure 5.16. Student 4’s data as it relates to sample location ............................................. 237

Figure 5.17. A compilation of all conjecture maps.......................................................... 239
Abstract

Culturally Relevant Education (CRE) focuses on the design of curricular materials that strengthen students’ cultural identities while teaching classroom content and science practices. While examples of CRE in science continue to grow, the identities and cultures of the designers are often different from those of the students and communities in which they work, leading to a divide concerning whose values are promoted in the classroom. Collaborative design invites diverse stakeholders to construct curricula that affirm multiple worldviews through distributing power within the design team. In this process, practitioners naturally adapt curricular materials depending on factors such as their instructor beliefs, institutional context, and student makeup. However, these adaptations are held in tension with the goals of the designer as a curriculum transfers to practice. Collaborative design considers adaptation as a mechanism that supports the transfer of curricular materials through mitigating power imbalances between designer and practitioner and exposing latent values that inform a design. Structures to study design and implementation of curricular materials remain sparse, leading to a focus on outcomes without paying attention to a multitude of factors that complicate the transfer of designs to real classrooms. The work presented herein examines the collaborative design and implementation process.

The first chapter expands on a fidelity of implementation framework, exploring the negotiation between critical components (e.g., a designer’s perceptions of what makes a curriculum effective) alongside participants’ contextualized knowledge needed for adaptation. To study this process, we partner with secondary science teachers and a research scientist in a workshop setting, qualitatively analyzing teacher reflections, interactions within the workshop, and adaptations made considering teachers’ context. This framework is then applied to an overarching collaboration between Ilisaġvik College, a Tribal College in Utqiaġvik, Alaska, and University of Michigan (UM) to design and implement a culturally relevant snow chemistry unit.

Chapters three and four define the critical components for the overarching collaboration, examining how scientific researchers portray the western scientific knowledge construction
process in relation to the Next Generation Science Standards (NGSS) alongside how tenets of CRE relate to the collaboration. These chapters analyze interview and classroom data using inductive-qualitative and case study methodologies to study frameworks of scientific epistemology and CRE. Findings dictate that more nuanced depictions of critical components are necessary to expose latent expectations and value sets that influence a design. Also, constructing spaces for negotiation between the designer and participant throughout implementation facilitates necessary adaptation while preserving the integrity of critical components.

The fifth chapter examines the negotiation between designer and participant context through the overarching collaborative design and implementation process between Ilisaġvik College and UM. This process is tracked over multiple semesters using conjecture mapping to structure analysis of support meetings of the design team, classroom interactions, and participant artifacts to inform adaptation based on context. Through collaborative design, the final implementation of the snow chemistry unit contains examples of students navigating Traditional Indigenous knowledge alongside western science practices, signaling the inclusion of multiple perspectives of science in the classroom. To reach this outcome, conjecture maps provide a structure for reflection on student interactions with the unit that inspired adaptations throughout multiple cycles of implementation. As a result, conjecture mapping facilitates the study of complex designs while considering multiple cultural perspectives, shedding light on how to design for cultural relevance in a way that affirms all stakeholders.
Chapter 1
Crossroads of Epistemology in the Classroom: A Case for Collaborative Design of Science Instructional Materials

1.1 Abstract

Students often struggle to learn science content because they perceive a divide between the content learned in classrooms and the values, practices, and beliefs in their everyday lives. In general, STEM education portrays the values and systems of a dominant Western science culture, undermining how these students experience the world. Culturally Relevant Education is a lens to develop curricular materials that strengthen students’ cultural identities while teaching content and scientific practices embedded within a classroom. Designers often develop culturally relevant materials by approaching the knowledge-construction process from multiple perspectives – using students’ cultural ways of knowing to reframe how students participate in science. This chapter presents a case for using collaborative design as a tool to incorporate diverse perspectives in the design and implementation process, offering guidance to designers as they construct materials in partnership with communities in which they serve.

1.2 Introduction

During the writing of this dissertation, the COVID-19 pandemic stunned the modern world (Mohapatra et al., 2020; Tooze, 2021). Through years of social isolation and uncertainty, the scientific community rallied and produced a series of vaccines that, in combination with other medical techniques, reduced the fatality rate to a point where society could operate while keeping the effects of the virus under control (Nature, 2021). Even with rapid deployment and high vaccine availability, one-third of the US population remains unvaccinated (Center for Disease Control and Prevention, 2022b; Mathieu et al., 2021; Our World in Data, 2022). Like many large-scale societal problems, the reasoning behind peoples’ hesitation is nuanced and
cannot be characterized by a single argument. Public perceptions regarding the effects of the vaccine caught the attention of Dr. Francis Collins, the departing director of the National Institute of Health. Collins indicated that the spread of misinformation about science “turned out to be a much more severe situation than (he) would have imagined” (Subbaraman, 2021, p. 373), listing it as a major concern as he departed the organization. While the scientific community made great strides throughout this period, the misunderstanding of the work of scientists prolonged the effects of the COVID-19 pandemic.

Individuals’ personal perspectives of science are influenced by their exposure to the scientific enterprise, which is often governed by their experiences in formal learning settings (Sandoval, 2005; Wickman, 2004). Current reform efforts, such as the Next Generation Science Standards (NGSS), dictate that students should learn core content through a series of Science and Engineering Practices (National Research Council, 2012; Osborne, 2014). These reforms guide teachers to create experiences for students that mimic the epistemic practices of Western scientists to ground their understanding of scientific knowledge construction and regulation (Duschl, 2008; Ford, 2008; Ford & Forman, 2006; Miller, Manz, Russ, Stroupe, & Berland, 2018; Windschitl, Thompson, & Braaten, 2008). However, in a study conducted five years after the NGSS were established, teaching practices amongst K12 educators remain similar to those reported prior to the standards’ release (P. S. Smith, 2020), showing that the reform’s vision is not transferring to practice even with a comprehensive effort to clarify how teachers should approach science instruction in their classrooms (Cerwin et al., 2018; McNeill, Affolter, & Reiser, 2022; Teacher Advisory Council and National Academies of Sciences Engineering and Medicine, 2016). Considering that reform efforts task teachers to convey science practices without prior experience in how science is conducted (Capps & Crawford, 2013), it is understandable that students’ classroom experiences would likely not be an accurate depiction of the work of scientists. These inaccuracies likely contribute to a greater misperception of how Western science is conducted, leading to greater societal problems such as the public response to the COVID vaccine rollout.

Layered in the public perception of science is a cultural component, where knowledge- construction in classrooms occurs in ways that are different from how students learn outside of school (Medin & Bang, 2014; National Academies of Sciences Engineering and Medicine, 2018). Often, classroom science emphasizes ways of knowing that are from European (e.g.,
Western) perspectives (e.g., the NGSS) (Ballenger & Rosebery, 2003; Medin & Bang, 2014; National Research Council, 2012), propagating a system of schooling that promotes certain value sets over others (Costanza-Chock, 2020; Kanu, 2006; L. T. Smith, Tuck, & Yang, 2018). This can present a barrier for students with non-Western identities in relating to traditional classroom science content and practices (Brown, 2004; Carlone & Johnson, 2007; Levrini, Fantini, Tasquier, Pecori, & Levin, 2015). Without critically examining the latent cultural values propagated by curriculum framed by modern reform efforts, students with perspectives that differ from the Western views of science may be unable to participate in the scientific process (Miller et al., 2018; Rosebery & Hudicourt-Barnes, 2006; Windschitl & Calabrese Barton, 2018) and identify with the discipline (Barton & Tan, 2010). The polarized response to the COVID pandemic is a product of an education system that privileges narrow perspectives of science, which fail to acknowledge and interact with alternative perspectives because they were not considered at most levels of the design and implementation process.

This presents a crucial design question: For whom do we design? Considering the question acknowledges the challenge of producing curricular materials that model scientific practices while relating to the diverse community value sets of the students that populate classrooms. The challenge involves clarifying what is meant by scientific practices, both in the Western science research laboratory and in the classroom, and providing experiences for teachers and students to learn how scientists conduct their work. It also involves inviting multiple stakeholders from the communities where we work to the design table, collaborating to make curricular materials that readily apply scientific practices while affirming multiple cultural perspectives. The work presented herein examines this collaborative design space.

To situate my work, I begin by discussing science practices, cultural aspects of science, and the incorporation of multiple epistemologies in a science classroom. After that, I detail how collaborative design methodologies can be a tool to structure the co-design of curricular materials that promote multiple epistemologies in the classroom. Finally, I provide an outline for my dissertation, offering a frame in which to view the collected body of work.

1.3 Knowledge Construction in Science

The core of Western science is the generation and validation of new knowledge on individual and social levels (Duschl, 2008; Lederman, 2013). Epistemology is the study of
knowledge and beliefs an individual holds about how knowledge is produced; scientific epistemology is a “description of the nature of scientific knowledge, including the sources of such knowledge, its truth value, scientifically appropriate warrants, and so forth” (Sandoval, 2005, p. 635). Since this understanding of scientific epistemology was clarified using a Western perspective, it is often viewed as acultural and value-free; however, all cultures possess a scientific epistemology (Medin & Bang, 2014). Anyone who interacts with science possesses a scientific epistemology, whether they are scientists, teachers, students, or someone from the general population (Duschl, 2008). Western scientific epistemology can be categorized into three perspectives: Disciplinary, Personal, and Practical.

1.3.1 Disciplinary Perspective of Epistemology

The disciplinary perspective of epistemology describes how the scientific field constructs scientific knowledge as a social practice amongst experts within a scientific discipline, focusing mainly on justifying theories or modifying concepts within their discipline (Duschl, 2008; Kelly, McDonald, & Wickman, 2012). In other words: scientists concern themselves with building from the work of fellow scientists to ground their research, using new data and tools to interpret data to inspire their work. For example, early in the COVID pandemic, scientists from various disciplines focused on learning about the transmission of the virus and preventing it’s spread (Li et al., 2020; Mecenas, Bastos, Vallinoto, & Normando, 2020; Wiersinga, Rhodes, Cheng, Peacock, & Prescott, 2020; World Health Organization, 2020). Researchers initially published conflicting results on the efficacy of masks both indoors and outdoors (Khosronejad et al., 2020; Sharma, Mishra, & Mudgal, 2020), as well as whether the virus remained on surfaces for extended time periods (Fiorillo et al., 2020; Lewis, 2021). As scientists collected, analyzed, and published data, the Center for Disease Control promoted guidelines that represented the consensus amongst the science community, shifting these guidelines as new data emerged about the pandemic (Center for Disease Control and Prevention, 2022a). In this case, the collective disciplinary epistemology worked together to construct and validate new knowledge with the goal of containing the spread of COVID.

1.3.2 Personal Perspective of Epistemology

The personal perspective of epistemology focuses on how learners conceptualize knowledge and how that influences their learning, specifically with personal views of truth rather
than what is established by the collective scientific discipline (Kelly et al., 2012). In this regard, an individual constructs their views of the scientific process through formal and informal experiences. Bell and Linn (2002) report that beliefs about science are shaped by available information, such as news accounts, textbooks, and materials published on the internet, where each source provides an account of authority and knowledge construction and offers varying degrees of bias that affect the presentation of results. For instance, early in the COVID pandemic, much of the general population was confused about the shifting perspectives on how to contain the spread of COVID. News and internet sources, which were the primary ways in which people learned about the pandemic, often differed in their sources and recommendations on preventative measures, such as masks (Ali & Qazi, 2022; Cohen, 2020; Janssen, Hendriks, & Jucks, 2021; Picheta, 2021). As a result, people formed varying perspectives on what the scientific community considered the most effective means of protection. The personal perspective also includes an individual’s conception of their academic domain (Sandoval, 2014), situating their personal perspective within the overall disciplinary perspective of their scientific domain (Hammer & Elby, 2002; Hofer, 2001). Continuing the COVID example, individuals who engage with scientific research responded to the recommendations made by scientists differently than the general public (Lavazza & Farina, 2020), understanding that knowledge in science shifts as new data becomes available (Kuhn, 1970; Lederman, 2013). Summarizing these two scenarios, people’s personal perspectives of scientific epistemology are highly dependent on the nature of their interaction with the scientific enterprise.

1.3.3 Practical Perspective of Epistemology

The interaction between disciplinary and personal perspectives describes a practical epistemology, where individuals participate in the socially shared practice of knowledge construction in a scientific discipline to solve particular problems in particular locations. Within this perspective, the individual is an active participant within a larger social paradigm, where the individual scientist and discipline work together to construct and validate new knowledge (Sandoval, 2014; Wickman, 2004). Discoveries in the COVID pandemic were made by individual scientists working from within a greater disciplinary paradigm. As the discipline produced new information about COVID, an individual scientist (or a team of scientists) used that information to ground experiments to collect data and make claims that shifted how the
discipline viewed COVID. Practical epistemology is also present in the classroom, where teachers use their experiences with a scientific discipline alongside their own personal perspectives to influence how they teach science content (National Research Council, 2012; Sandoval, 2014), therefore affecting students’ perceptions and experiences with science (Wickman, 2004). This type of practical scientific epistemology engages students in an epistemic activity that mimics scientific practices so people can better understand the work of scientists (Ford, 2008; Ford & Forman, 2006; Kelly & Licona, 2018).

1.3.4 Scientific Epistemology in Relation to the NGSS Science and Engineering Practices

The Framework for K-12 Science Education (2012) focuses on teaching disciplinary core content using eight Science and Engineering Practices, improving upon previous reform efforts by clarifying that the scientific process involves a set of regularly used practices by scientists to model scientific epistemology in the classroom. For instance, the Framework (2012) discusses that Engaging in Argumentation from Evidence is an “essential element both for building new knowledge in general and for the learning of science in particular…as all ideas in science are evaluated against alternative explanations and compared with evidence” (National Research Council, 2012, p. 44). This Science and Engineering Practice engages students in the social learning practices of scientists, where students publicly convey their ideas while critiquing other students’ claims to understand the nature of scientific claims (Ford & Forman, 2006). The argumentation process, generally performed within classroom environments, contributes to students’ personal perspectives. The practical and disciplinary perspectives require active participation from within a community that utilizes specialized knowledge. Because students and teachers often do not have access to these disciplinary communities, they often struggle to portray how the Science and Engineering Practices are applied in discipline-specific ways to construct new knowledge (Capps & Crawford, 2013). However, even though students may not interact with the specialized knowledge needed to grow their practical and disciplinary perspectives, they may still be thinking scientifically from a perspective that expands beyond the Western model (Rodriguez & Morrison, 2019).
1.3.5 Cultural Perspectives of Science

Science is cultural—throughout modern history, people from cultures around the world engage in science practices to understand the world around them (Harding, 1994; Medin & Bang, 2014; Traweek, 1996). For instance, the Iñupiaq people built a deep body of knowledge over thousands of years that have helped them thrive in the harsh climate of the Northern Arctic (Aikenhead & Jegede, 1999; Ascher, 2002; Eglash, Bennett, O'Donnell, Jennings, & Cintorino, 2006; Erickson, 2020). To do this, they engaged in scientific practices to learn about their environment and successfully transferred their knowledge between generations through culturally embedded learning processes (Barnhardt & Kawagley, 2008; Erickson, 2020; Wohlforth, 2005). For instance, to procure food to survive, Iñupiaq whalers made note of the migration patterns, signs for open water in sea ice, weather patterns, and systems to hunt whales using harpoons and boats constructed from what is remaining from other subsistence hunts (e.g., caribou, seals) (Wohlforth, 2005). To transfer this knowledge, Iñupiaq youth personally experience all that whaling involves while being taught and protected by family and community members (Bodenhorn, 1997). Storytelling and dancing are also ways in which the knowledge is transferred in their community (Ascher, 2002; Eglash et al., 2006; Erickson, 2020). This knowledge, called Traditional Ecological Knowledge, distinguishes itself as Indigenous peoples’ ways of knowing (Barnhardt, 2005; Barnhardt & Kawagley, 2008; Cajete & Bear, 2000). It embodies similar scientific practices as their Western counterparts (Barnhardt & Kawagley, 2008), with the primary difference being that the Western world clarified their perspective of science and systematically privileged their viewpoint over others in the modern era (Grande, 2015; Herrenkohl et al.; Medin & Bang, 2014).

Promoting the Western perspective of scientific epistemology within reform documents, such as the NGSS, indirectly results in a limited view of who participates in science and what counts as science (Carlone & Johnson, 2007; Medin & Bang, 2014). This exclusionary view means students often need to assimilate into Western Science as it is presented to them (Brown, 2004; Levrini et al., 2015) instead of utilizing their own cultural resources (Moll, Amanti, Neff, & Gonzalez, 1992) to approach science in the classroom (Aronson & Laughter, 2016). Teachers will often present scientific problems with a singular solution and problem-solving pathway in mind. For example, when teaching dimensional analysis, teachers will focus on heuristics, such as the mole map (LibreTexts, 2022), to train students to focus on units for conversions.
Dimensional analysis is a lesson in proportional reasoning where multiple pathways exist to mathematically solve such problems (AMTA, 2021). Yet, teachers often focus on and assess students according to a singular path (e.g., the mole map) even though students may have a reasonable alternative explanation. This approach develops a students’ personal perspective of scientific epistemology that includes singular answers and facts instead of an understanding of knowledge construction (Barton & Yang, 2000). Such approaches bolster perspectives to schooling that promote cultural assimilation instead of democratic approaches to learning (Bang, Brown, Calabrese Barton, Rosebery, & Warren, 2017; Kanu, 2006), and can lead to positivist societal perspectives that science is about fact-finding instead of a series of practices that help us understand the world (Zeidler & Lederman, 1989). When considering societal responses to the COVID pandemic, this ‘fact finding’ perspective could explain how people believe that scientists change their mind about a settled idea (Farr, 2020) instead of the disciplinary epistemology shifting as scientists gathered more data and participated within their respective community (Bak-Coleman & Bergstrom, 2022), engaging their practical epistemology.

1.3.6 Examples of Multiple Representations of Epistemology

There is a need to develop science curricula that incorporate multiple perspectives of epistemology with science content (Medin & Bang, 2014) and access students cultural resources instead of promoting assimilation (Barton & Tan, 2009; Brown, 2006; Brown & Kelly, 2007; Carlone & Johnson, 2007; Medin & Bang, 2014; Moll et al., 1992). One approach is culturally relevant education (CRE) (Aronson & Laughter, 2016; Delpit, 2006; Gay, 2018; Ladson-Billings, 1995, 2004, 2006; Paris & Alim, 2017), which promotes curricular structures that affirm the interaction of cultural references with classroom content, structure critical reflection and cultural competence in the classroom, and call attention to power imbalances that bolster systemic inequity throughout education. CRE engages students from within their cultural perspectives (Bang, Faber, Gurneau, Marin, & Soto, 2016; Calabrese Barton et al., 2021). For example, Bang et al. (2016) designed a science learning experience for Indigenous populations that involved learning about ecological systems through instructional practices grounded in Indigenous ways of knowing. In this activity, participants read Indigenous stories that promoted a more holistic and transgenerational approach to the life cycle and then engaged in a learning walk around the forest to notice this perspective in the ecosystem around them (Bang et al., 2016). From this
experience, students generated cross-epistemological dialogue where they discussed scientific content through their Indigenous cultural lens. In another example, Calabrese Barton et al. (2021) worked with an urban community center to engage participants in a design project considering ways to use grant money to improve their center. In this project, participants engaged with multiple stakeholders to determine which improvements were most important for their community center, presenting their findings to influence the outcome of the project while modeling engineering design (Calabrese Barton et al., 2021). In both instances, students exhibited epistemic agency (Miller et al., 2018) while engaging from their cultural perspective, learning how to navigate structures of power within their community and multiple perspectives on a specific problem, while learning about scientific epistemology. These outcomes align with the tenets of culturally relevant education (Aronson & Laughter, 2016).

In these cases, specific shifts to the traditional design process led to a more equitable product that promoted multiple, diverse perspectives, while “attend[ing] to the ways in which normatively powered dynamics are reinscribed in the roles and relations between researchers and 'the researched,' and deliberately work[ing] to disrupt or create new roles and relations to achieve transformative ends" (Bang & Vossoughi, 2016, p. 174). Extending this perspective, collaborative design techniques expand who is invited to the design team, leading to the design of curricular materials that affirm cultural value sets while engaging students in their personal perspectives of scientific epistemology instead of conveying disciplinary perspectives apart from students’ culture and everyday lives.

1.4 Design and Implementation Methodologies

1.4.1 Fidelity of Implementation and Adaptation

Mechanisms that distribute power to multiple stakeholders within the design process is atypical in design and implementation research. Oftentimes, the transfer of curricular materials involves structures that privilege researchers’ expertise and perspective over that of their participants (Bang & Vossoughi, 2016, p. 174; Penuel & Fishman, 2012; Penuel et al., 2020). Penuel et al. (2020) report that education policy over the past two decades focused on building infrastructure to transfer ‘research-based’ educational practices using methods that distanced the researcher from the participant to avoid bias and potential scrutiny as innovations go to scale (Nzinga et al., 2018; Penuel et al., 2020; Peurach, 2016; Peurach & Glazer, 2012). This
distancing led to frameworks like fidelity of implementation, which propose the identification of components that make an innovation effective, defined as \textit{critical components}, and measuring the extent to which the implementers are faithful to those components (Century, Rudnick, & Freeman, 2010; Lastica & O’Donnell, 2007; Stains & Vickrey, 2017). Because innovations that were effective in the pilot stages of development became ineffective as they transferred into practitioner contexts, researchers suggested that practitioners unknowingly remove the components that make an innovation effective as it is transferred into practice (Stains & Vickrey, 2017). While the fidelity of implementation framework mentions \textit{moderating variables} as contextual factors that influence the design, they often mention these factors as impediments to successful implementation, leading to deficit orientations towards practitioners instead of considering context as a normal and critical part of the design process.

Teachers operate within a system of social structures and hold professional beliefs that affect their curriculum. For example, as previously mentioned, the NGSS tasks teachers with the implementation of curricular materials that explore disciplinary core ideas through the Science and Engineering Practices (National Research Council, 2012). Teachers’ beliefs (Luft & Roehrig, 2007) can include perspectives on teaching that may prioritize the communication of key content using traditional, teacher-focused techniques (e.g., lecture). Teacher training programs often don’t provide teachers with the experience necessary to accurately represent the Science and Engineering Practices (Capps & Crawford, 2013). Administrative and classroom structures could also impact implementation even if the teachers’ beliefs and experience align with the Science and Engineering Practices (Allen & Penuel, 2014; Henderson & Dancy, 2007). For instance, a teachers’ administration could have specific viewpoints on how to teach science or bell schedules could limit the amount of continuous time spent on classroom instruction. Adaptation of curricular materials naturally occurs in light of contextual factors, where teachers engage in sensemaking to negotiate between the intended curriculum and the expectations of the structures surrounding the teacher (Allen & Penuel, 2014; Remillard, 2005; Stein, Remillard, & Smith, 2007). Failing to consider participants’ background and context in the design process often results in products that align with current reform efforts but do not transfer to practice due to variables outside of the designers’ control (Allen & Penuel, 2014; Henderson & Dancy, 2007; Penuel & Fishman, 2012).
1.4.2 Positionality of the Designer

Another implication for positioning the researcher as expert in the design process is the potential for the inclusion of unexamined and hidden cultural value sets that privilege certain worldviews over others (Costanza-Chock, 2020; Esmonde & Booker, 2016), which lead to latent biases that exclude students (Carlone & Johnson, 2007; Medin & Bang, 2014). To help characterize this phenomenon, examples from the engineering design space show the outcomes of products that were designed without regard for their users. In one example, engineers designed water filters for remote villages in Haïti without consideration for how the people would actually use the devices, assuming the villagers had access to certain household items and parts to fix the filters if they broke. A majority of the filters remained unused, suggesting that culturally-appropriate initial and follow-up education for the users alongside an early assessment of the resources available to villagers would have changed the outcome of the project (Sisson, Wampler, Rediske, & Molla, 2013). Similar culturally-insensitive engineering designs led to the propagation of systemic inequities affecting non-majority populations (Costanza-Chock, 2020). To avoid replicating these design mistakes, engineers now consider community-based and collaborative design techniques, such as user experience (UX) design principles, as standard practice before a product goes to market (Costanza-Chock, 2020). Similarly, design and implementation techniques that include multiple stakeholders are emerging in education spaces to disrupt the power imbalance of the traditional design process.

1.4.3 Collaborative Design

Collaborative design processes (Penuel et al., 2020) recognize the complex ecosystem that surrounds the designer as they conduct their work. This family of approaches share “new ways to organize the enterprise of education research to be more of a “two way street” between researchers and key stakeholders in the improvement of practice” (Penuel et al., 2020, p. 631; Tseng, Easton, & Supplee, 2017; Tseng, Fleischman, & Quintero, 2017). These practices call upon a range of stakeholders, from community members, teachers and instructors, students, administrators, and researchers, to be involved in the design process and inform what is taught in learning environments. Penuel et al. (2020) propose a series of principles that guide the collaborative design process, including a recognition that designs should provide practical value
to participants and their organizations or communities. In tandem with the other principles, the collaborative design process produces knowledge about learning environments with special attention to context and is iterative and collaborative with multiple stakeholders. The multiplicity of voices decenters the designer’s perspective and provides a contextual lens through which to adapt and sustain innovations in specific learning environments. Considering the importance of including community value sets when designing for CRE (Aronson & Laughter, 2016) and the socio-political history of non-majority communities around the United States (Esmonde & Booker, 2016), collaborative design processes resituate the power dynamics of design so that multiple stakeholders have voice and agency to control the outcome of the innovation. This distribution of power allows a natural pathway for researchers to learn about and engage deeply with the communities in which they partner.

1.5 Dissertation Outline

The second chapter explores the concept of fidelity of implementation through a workshop conducted with preservice high school teachers. In this chapter, we suggest expanding the framework to include the critical knowledge of the participants alongside the critical components determined by the designer. We also recommend a space of negotiation where participants and designers adapt curricular materials in response to participants’ context while preserving what makes an innovation effective. I represent the three components in Figure 1.1, serving as an outline for the rest of the dissertation, where we detail a collaborative design project between Ilisaġvik College, a Tribal College in Utqiaġvik, Alaska, and the University of Michigan.

Chapters 3 and 4 detail what we consider to be critical components for a collaborative design project, highlighting our values as we approached the design and implementation process. The third chapter provides a nuanced depiction of the Science and Engineering Practices as an embodiment of scientific

![Figure 1.1. A summary of the expanded fidelity of implementation framework.](image-url)
epistemology, looking into how science and engineering professors represent their discipline in modules designed for preservice secondary teachers. The fourth chapter clarifies our perspective of culturally relevant education applied to the context of Utqiagvik, Alaska, and considering the integration of traditional Indigenous and local knowledge alongside the scientific perspective. These chapters shed light on the multiple epistemologies that are represented in the project.

The fifth chapter describes how we considered critical knowledge and created a space of negotiation within the partnership between Ilisagvik College and University of Michigan. In this chapter, we track the design and implementation of a snow chemistry unit used by our collaborators in Alaska. We discuss the critical knowledge learned from interactions with our collaborators and how we created space for adaptation throughout four years of partnership. This process was iterative, with multiple instances where we adapted our design to better align with our participants’ needs, perspectives, and context. We track our design using conjecture mapping (Sandoval, 2014), helping us consider specific activities in the design throughout the partnership and how these activities encouraged the inclusion of multiple perspectives within the science classroom.

Through this work, I provide an example of how collaborative design processes can move the field of chemistry education, and discipline-based education research as a whole, beyond frameworks like fidelity of implementation. These fields can shift to incorporate and adapt curricular resources, to include multiple perspectives of scientific epistemology, and to construct more equitable classrooms that are inclusive to all students.

1.6 References


Chapter 2
Moderating Variables and Fidelity of Implementation: The Use of Teacher Sensemaking to Guide Adaptive Curriculum Design

2.1 Initial Remarks

This chapter examines how workshop participants interpret and enact designed components of a curriculum. Especially within discipline-based education fields, evidence-based instructional practices are often presented to workshop participants with little consideration for the participants’ context, leading to a perspective that if a design fails to achieve its intended outcomes in the real world, it is because the participant removed what makes a curriculum effective. However, research shows that adaptation naturally occurs as an innovation transfers to teaching practice, considering the participants’ students, classroom and administrative contexts, and their beliefs on teaching and learning as they implement in their classroom. This study examines a workshop that occurred at the University of Michigan, demonstrating a curriculum intended to embody the Science and Engineering Practices from the Next Generation Science Standards and relevance through snow chemistry disciplinary practices. An environmental chemistry research professor designed the materials initially for their introductory undergraduate classroom with the desire to learn about shifts that could be made to make the materials accessible for secondary teachers. Workshop participants included secondary science teachers from two local schools in the same city as the university. The two-day workshop followed a structure where the teachers experienced the materials as students, adapted the materials in a collaboration session with the designer, and taught the materials to students invited from one of the area high schools.

This study was guided by a fidelity of implementation framework published in a leading discipline-based education research journal, studying how a curriculum transfers to practice based on the designer’s perspective on the critical components, or what makes curriculum
effective. The framework splits critical components into two categories: structural and instructional. Structural critical components focus on the organizational components of a curriculum, such as materials used and curriculum guides. Instructional critical components focus on the behavioral aspects of a curriculum, such as perceived student and teacher behaviors. This theory guided the data collection and analysis, as the authors aimed to determine whether teacher interpretations of the critical components aligned with the designers’ intentions from within the workshop. Critical components were qualitatively analyzed using teacher interactions with the curricular materials throughout the workshop, focus groups conducted within the workshop, and reflective journals throughout the workshop.

Results show that the teacher’s and designer’s perceptions of critical components from within the workshop aligned, however teacher participants’ contexts limited the extent to which the critical components could be applied outside of the workshop. Teacher participants recognized the importance of teaching content through relevant projects that relate content to disciplinary practices, reflecting that they thought that the snow chemistry technique could engage students in projects that embodied research practices. However, teachers vocalized that features such as alignment with secondary curriculum in their schools, characteristics of their student populations, and structure of the school day influences how the materials could be applied within their context. Teachers willingly offered suggestions on ways to shift curricular material based on contextual features and, when given the space, collaboratively adapted the materials with the designer to negotiate between their contexts and designer expectations of the critical components. These results align with greater education research focusing on teacher sensemaking and adaptive curriculum design.

The results from this study suggest that the critical components, as defined by the fidelity of implementation framework, are limited since they privilege the perspective of the designer. This study proposes an extension to the framework to include learning about participants’ critical knowledge, or contextual features that are necessary to consider for implementation, and spaces of negotiation, where participants and designers collaboratively adapt for context while preserving the critical components of a curriculum. This work provides insight into ways in which the power dynamic between designer and participant can become more balanced, suggesting collaborative design methodologies to build upon the fidelity of implementation framework.
This chapter was submitted to the discipline-based education research journal as a response to the initial fidelity of implementation framework. Dr. R. Charles Dershimer and Prof. Ginger Shultz were responsible for structuring the workshop and data collection. The author independently completed all remaining work, including data analysis, post-workshop coordination with the teachers, and manuscript writing.

2.2 Abstract

Fidelity of Implementation as a framework for curricular transfer has gained momentum in discipline-based education research to consider how critical components transfer during the implementation of curricular resources. While efficacy may indicate whether a specific innovation works within a particular context, the designer's voice is often privileged over the contextual needs of the stakeholders who implement the innovation. This article details a professional development workshop for secondary science teachers that focused on applying an environmental chemistry technique to portray the NGSS Science and Engineering Practices. During the workshop, teachers reflected on pedagogical and contextual considerations while engaging with a learning, collaboration, and teaching process mediated by reflective journals and focus groups. Analysis of the data suggests that teachers consider critical components from within their contextualized perspective, utilizing spaces within the workshop to adapt curricular resources that better suit their needs. Reflecting on this implication, we propose an expanded fidelity of implementation framework to incorporate teacher voice and to advocate for collaborative design alongside our participants.

2.3 Introduction

_We’ve gotta get through this topic by a specific time, and also — things are changing. So many pieces are changing and it's overwhelming, between AP (Advanced Placement), IB (International Baccalaureate), and the NGSS (Next Generation Science Standards) it’s tough to consider how we can fit this in._

Jocelyn voices as she participates in a focus group. Similar to many other secondary teachers, she would like to implement more evidence-based instructional practices (EBIPs) in her classroom. Still, she feels conflicted as she navigates the expectations of her teaching context alongside what she is learning in the professional development workshop. On the other hand, workshop designers wonder how to best present EBIPs so that participants transfer what they
learn into their classrooms without compromising the components that make an EBIP effective (Century, Rudnick, & Freeman, 2010; O’Donnell, 2008). This study explores the tension between designer expectations and participant teaching context during a workshop focusing on relevance, NGSS Science and Engineering Practices, and disciplinary practices.

Typically, researchers determine the impacts of EBIPs by measuring differences in outcomes between a class taught using an EBIP and another class that serves as a “control” classroom. These studies capture an overall success of the EBIP, but many do not shed light on why, how, and under what conditions the EBIP is successful compared to the control classroom. Expanding implementation of the EBIP across settings generally occurs under the assumption that EBIPs are taught by instructors in a standardized fashion as intended by the designers in all settings (Century et al., 2010). Reality often muddles the validity of claims that support the impact of EBIPs because instructors regularly adapt curricular materials based on moderating variables that include class size, available resources, and personal beliefs on teaching and learning (Andrews & Lemons, 2015; Henderson & Dancy, 2007; Lund & Stains, 2015). In response, the U.S. Department of Education and the National Science Foundation call for the measurement of Fidelity of Implementation (FOI) when determining the impact of an EBIP through the analysis of variations of FOI and intervention outcomes (Institute of Education Sciences, 2013).

In a recent Essay published in this journal, Stains and Vickrey (2017) pose a compelling framework to guide the discipline-based education research community in conceptualizing FOI to support the successful propagation of an EBIP. Drawing from studies on FOI from the broader education field (Century et al., 2010; O’Donnell, 2008), the authors define FOI as the “extent to which the critical components of an intended educational program, curriculum, or instructional practice are present when that program, curriculum or practice are enacted” (Stains & Vickrey, 2017, pp. 2-3). Therefore, a major part of their framework includes a process for identifying the specific components that make an EBIP effective (e.g., critical components) and measuring the extent to which the implementers are faithful to those components. Additionally, contextual factors which may influence the successful implementation of an EBIP (e.g., moderating variables) should be “characterized, measured, and integrated into the analysis of the relationship between FOI and intervention outcomes to comprehensively characterize the reasons and context behind the success of an intervention” (Stains & Vickrey, 2017, p. 4).
This article explores the FOI framework within the context of a two-day workshop where high school teachers learned about a specific EBIP previously implemented in a university setting and collaborated to adapt the practice for secondary students. In particular, we analyze the collaborative sessions by employing teacher sensemaking (Allen & Penuel, 2014) to learn more about how a teacher interacts with a curricular resource while they consider their teaching context.

2.3.1 Fidelity of Implementation Framework

The framework for measuring FOI proposes determining the critical components and moderating variables of an intervention (e.g., a specific EBIP) and then measuring the extent to which the implemented intervention follows the intended critical components (Figure 2.1). During the pilot stage of implementation, a researcher or intervention designer can identify the critical components and moderating variables by leveraging empirical studies, consulting experts, and conducting qualitative research (Mowbray, Holter, Teague, & Bybee, 2003; Stains & Vickrey, 2017). There are two categories of critical components: structural and process (Century et al., 2010).

![Figure 2.1. A summary of the Stains and Vickrey (2017) Fidelity of Implementation framework.](image-url)
Structural critical components include considerations the designer makes relating to the organization and structure of an intervention and separates them into procedural and educative subcategories. The procedural subcategory describes the designer’s intent regarding what the instructor should do during implementation of the intervention. It includes descriptions of how the curriculum or practice is intended to be implemented with attention to procedures and organizational features of the intervention. Potential examples of this include the expected timeline and order of the intervention, curriculum guides and materials, and the makeup of the curricular materials. The educative subcategory considers what background knowledge instructors must possess to achieve FOI of the curriculum or practice from the designer’s perspective. Examples include content knowledge, pedagogical knowledge, pedagogical content knowledge, and teacher beliefs.

Process critical components, sometimes referred to as instructional critical components, indicate designer expectations for how the intervention will be implemented during instruction. It is split into two subcategories: pedagogical and student engagement. The pedagogical subcategory discloses the designer’s perception of how the instructor should behave and interact with students when implementing the curriculum or practice. Examples include intentional interactions with students around the content, facilitating a whole-class discussion, and using empirical data to ground student learning of content material. The student engagement subcategory includes the designer’s expectations for how students interact with the instructor, materials, or classmates. Examples of this include students’ potential questions about materials, small-group discussion topics, and developing strategies to solve problems.

Moderating variables are components outside of the intervention itself that play a role in implementing the curriculum or practice (Century et al., 2010). Previous research reveals that moderating variables occur at multiple levels in the transfer of the intervention from workshop to an instructor’s practice. For instance, facilitation strategies, quality of delivery, and participant responsiveness are variables at the workshop-level that could affect implementation (Carroll et al., 2007). Participants who learn an intervention are individuals with unique characteristics and beliefs about teaching and learning that may result in adaptation to the program (Lund & Stains, 2015; Ruiz-Primo, 2006). Participants who eventually transfer curricular materials to their teaching context function within a greater academic structure that have norms and expectations that are context specific. For instance, classroom structure, student cultures and behaviors,
expectations of content coverage, and evaluation structure are all variables that shift drastically depending on the institution (Henderson & Dancy, 2007).

2.3.2 Research Questions

We assert that a critical element is missing from the discussion of FOI and the influence of moderating variables in the implementation process; the voice of the users (e.g., instructors who will be using the design products) who implement the curriculum or practice in their own classrooms. Scanlon et al. (2019) discuss that the aforementioned FOI framework “emphasizes the flow of information from the [designer] to the instructor about how the practice should be implemented” (Scanlon et al., 2019, p. 2) and recommend that the reverse flow should also occur to inform designers about implementing interventions in diverse, real-world contexts. Even when policy-makers and curriculum designers make an effort to align curriculum, reform efforts, and professional development, teachers’ judgments about coherence between standards and professional development, as well as contextual factors such as school environment, have a major influence on the implementation of curricular materials (Allen & Penuel, 2014; Penuel, Fishman, Gallagher, Korbak, & Lopez-Prado, 2009). Considering that contextualized adaptation of an intervention is recognized as inevitable in FOI research (Century et al., 2010; O’Donnell, 2008; Stains & Vickrey, 2017), little advice is offered to ensure that critical components as conceptualized by the designers, which are crucial to the success of an intervention, remain after implementation in real classroom environments. The inclusion of users in the design process could be a way to ensure that critical components remain while contextualized adaptation occurs to ensure the success of a curriculum or practice.

In this study, we set out to document and analyze the ways in which users interact with and adapt the critical components of a curriculum, as determined by the designers, due to moderating variables and contextual information. Specifically, we ask:

1. How do users interpret the critical components of a curriculum?
2. What features do users consider when adapting curricular materials to their context?
2.4 Methods

2.4.1 Research Context

The workshop took place at a large, research-intensive Midwestern university in August 2017. Curricular materials were adapted from a lesson that was a part of a first-year introductory general chemistry laboratory course designed to teach acid-base content while modeling disciplinary practices in snow chemistry (May et al., 2018). The lesson’s design team consisted of an assistant research professor and a graduate student who conduct environmental chemistry research. In addition, the workshop’s design team consisted of an assistant research professor located in a science department who conducts chemistry education research, a clinical instructor who coordinates secondary education teacher training at the school of education, and a graduate student with experience teaching in secondary schools and facilitating teacher training workshops. The workshop's focus was to gain feedback on a lesson involving a precipitation titration using the Mohr method (Ibanez, Hernandez-Esparaza, Doria-Serrano, Fregoso-Infante, & Singh, 2008) to analyze chloride concentration in environmental samples. We chose this particular lesson because: (1) the materials are readily available in high school settings within the state in which the workshop was conducted, making the lesson accessible to most teachers; (2) titration is taught in most secondary chemistry classrooms as a way to quantitatively determine concentrations of acids and bases, so most students and teachers would be familiar with the experimental protocol; and (3) the Mohr method is sensitive enough to detect chloride concentrations in most environmental settings, allowing flexibility in framing the technique as a tool to invite students as participants in a number of the NGSS Science and Engineering Practices (SEPs) (National Research Council, 2012), as summarized in Table 2.1. In conducting the workshop, the design team wanted feedback from teachers on how the Mohr method could be used to help students at both secondary and postsecondary levels engage in practices that resemble authentic research in environmental chemistry.

2.4.2 Identification of Critical Components

Aligning with Stains and Vickrey (2017), we examined previous empirical research, consulted with experts, and utilized qualitative methodology to identify the critical components represented within the lesson from the designers’ perspective. This lesson was designed to
provide students an opportunity to engage in disciplinary practices (Ford, 2008; Ford & Forman, 2006) in environmental chemistry, as related to the SEPs (National Research Council, 2012), through relevance and authentic application of content material (Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013). Table 2.1 summarizes these connections between the SEPs and the lesson and was used to promote discussion with all participants in the workshop.

### Table 2.1. List of Science and Engineering Practices and how they relate to the Mohr Method analysis technique.

<table>
<thead>
<tr>
<th>Science and Engineering Practice</th>
<th>Mohr Method Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Asking Questions and Defining Problems</strong></td>
<td>Students can choose a research question or problem that is important to their local community, which could influence where they collect samples</td>
</tr>
<tr>
<td><strong>Developing and Using Models</strong></td>
<td>Depending on the level of the course, students can create models representing how chloride selectively precipitates to chromate prior to silver ions due to the solubility products constant ($K_{sp}$)</td>
</tr>
<tr>
<td><strong>Planning and Carrying out Investigations</strong></td>
<td>Based on their research question or problem, students can develop an experimental protocol for how they collect samples. Depending on the concentration of chloride in solution, students can make choices on the concentration of titrant</td>
</tr>
<tr>
<td><strong>Analyzing and Interpreting Data</strong></td>
<td>Students analyze their collected data and can crowdsource with the rest of the class to expand the data set. Simple trendlines can be generated without statistics</td>
</tr>
<tr>
<td><strong>Using Mathematics and Computational Thinking</strong></td>
<td>Data points that were generated could be placed in a database and shared year after year. Statistics computations can be used to generate trendlines and comparisons</td>
</tr>
<tr>
<td><strong>Constructing Explanations and Designing Solutions</strong></td>
<td>Based on the dataset, students can present their findings to other groups to discuss their patterns/trends and explanations on why the patterns/trends are present</td>
</tr>
<tr>
<td><strong>Engaging in Argument from Evidence</strong></td>
<td>Teachers can structure discourse in a way that students discuss their findings based on evidence and receive feedback from their peers</td>
</tr>
<tr>
<td><strong>Obtaining, Evaluating, and Communicating Information</strong></td>
<td>Research articles from primary literature that show how students engage in the scientific process could be generated for students. Students could read news articles with peer review articles to contrast claims made with the evidence that is present. Posters, presentations, seminar sessions could be platforms for students to engage in communicating their findings</td>
</tr>
</tbody>
</table>
The procedural critical components were modeled through physical resources and example plans for a lesson. The organization of the workshop materials focused on providing Participating teachers with resources to conduct the lesson in their classrooms, including a PowerPoint presentation, worksheets, and laboratory kits that included the necessary supplies to perform the lesson in the teachers’ contexts after the workshop. We also modeled the lesson plan (as intended by the designers) to the teachers within the workshop. A major consideration for the educative critical components was that many teachers are asked to display disciplinary practices in their classroom without much training or background in how those disciplinary practices are applied in relevant contexts (Anderson, 2007; Capps & Crawford, 2013). For instance, while we could assume that the teachers in the workshop were familiar with the SEPs since their nature is ubiquitous in secondary education, we could not assume that they have experienced the SEPs as they are applied in authentic laboratory settings. As a result, we designed instances in the workshop where teachers and environmental scientists interacted to promote discussion of disciplinary practices and their authentic application.

For the student engagement critical component within this lesson, it was important that we design materials to promote student agency in the scientific process, helping them make decisions that affected the outcomes of the experimental design (Corwin et al., 2018; Pickering, 2010), which is true of many lessons where students model disciplinary practices. During this lesson, students made choices based on their personal interests and what they understood about their local environment when they developed their research question, when they constructed sampling plans based on their knowledge of their geographical location, and when they designed and presented their explanations of data to their classmates and/or a wider audience (Table 2.1).

In the pedagogical critical component for this lesson, the role of the teacher became that of a facilitator, guiding students’ ideas and ensuring understanding of the titration procedure (e.g., the

<table>
<thead>
<tr>
<th>Pseudonym</th>
<th>School</th>
<th>Context</th>
<th>Classes Taught</th>
<th>Teaching Experience (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Johnny</td>
<td>Lakeview School (6-12th grade)</td>
<td>Private</td>
<td>AP Chemistry, Chemistry</td>
<td>25</td>
</tr>
<tr>
<td>Jocelyn</td>
<td>Central High School (9-12th grade)</td>
<td>Public</td>
<td>AP Chemistry, Chemistry, Biology</td>
<td>15</td>
</tr>
<tr>
<td>David</td>
<td>Lakeview School (6-12th grade)</td>
<td>Private</td>
<td>Chemistry, Physics</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 2.2. Workshop participant information.
Mohr method), which we presented as a tool scientists use to find concentration, for students to analyze their samples

As a result of empirical research planning and interviews of the science experts who designed the lesson (Supplemental Material), we summarize the proposed critical components as (1) learning disciplinary practices of environmental chemistry through (2) problems that are relevant to students and (3) the NGSS SEPs. The results of this article represent qualitative research that was conducted to finalize and operationalize the critical components of the lesson.

2.4.3 Participants and Teaching Contexts

The clinical instructor at the school of education recruited high school science teacher participants from their network of mentor teachers interested in learning about activities that align with the SEPs. The three participants taught at two high schools in the same city as the research institution. Their information can be found in Table 2.2. All participants consented through IRB protocol, and we applied pseudonyms for their names and schools to protect their identity. We offered teachers stipends for their participation in the workshop and kits that included supplies necessary to perform the lesson in their own classroom.

Central High School is a public school that serves approximately 2,000 students (9-12th grade) in the town in which the research university is located. The student population at Central is roughly 20% African American, 20% Asian, 10% Latino, 10% Multiracial, and 40% White, with 21% on free and reduced lunch (website). Central High School is considered a high-performing high school, with roughly 80% of its students scoring proficient or above on reading and math test scores and an average ACT score of 30 (mishcooldata.com, 2018). Central High School offers AP, IB, and dual enrollment courses with a local community college. Lakeview School is a private school that serves approximately 500 students (6-12th grade) from the region around the town in which the research university is located. While specific demographic data could not be located, 50% of students self-identify as students of color, and 20% receive financial aid (school web page). Lakeview School offers a wide range of enrichment opportunities (e.g., robotics team, sustainable engineering programs) and an AP program. The average ACT score was 31 (school web page). While the teachers come from both private and public contexts, their institutions have similarities that make collaboration meaningful for the teachers. Notably, both schools’ science departments were working towards aligning their
curriculum to the NGSS standards and finding opportunities to model authentic science practices within their classroom.

The teachers recruited twelve graduated seniors from both schools who took chemistry the prior year to be model students in the adapted activity on the second day. Students gave consent through IRB protocol to be videotaped and recorded. However, we did not use their information in the analysis because our focus was on teachers’ interaction with curricular materials. We offered lunch and a raffle for a gift card as an incentive to participate in the workshop.

2.4.4 Workshop Context

Instructors and teachers are not isolated individuals who function within a controlled system. Throughout the day, they operate within a system of social structures (e.g., professional interactions, department initiatives, interactions with students) and have professional beliefs that affect their enacted curriculum. These structures rarely align, so instructors and teachers need to

---

**Workshop Structure**

![Workshop Structure Diagram]

**Data Collected**

- Video recording of presentation of lesson
- Video recording of lab session
- 1-hour reflective focus group after laboratory session
- Written journal reflections
- 3-hour teacher collaboration session
- Documents of adaptation
- Video of the laboratory with local high school students
- 1-hour reflective focus group after laboratory session
- Written journal reflections

*Figure 2.2. Structure of the workshop and summary of the collected data.*
“engage in sensemaking to resolve ambiguity and manage uncertainty within their environment to make retrospective, as well as prospective sense of change” (Allen & Penuel, 2014, p. 137). For instance, in a study of teachers implementing NGSS-inspired curricula at a large, urban district, Allen and Penuel (2014) found that teachers regularly engage in sensemaking to resolve incoherence between the district, school, and classroom in categories such as conflicting goals, absence of measures aligned with the NGSS that can be used as assessments, limited resources, and lack of clarity on how to support students’ engagement in the NGSS. We developed the teacher workshop to capture instances of teacher sensemaking and learn about how teachers consider context while learning a new instructional lesson. The two-day workshop consisted of two parts and is summarized in Figure 2.2.

The goal of Day 1 of the workshop was for the teachers to learn the lesson's curricular materials from the student's perspective. We presented the lesson to the teachers in terms of the research design process in Figure 2.3. The top half of the research process depicts a focus from broad to narrow. The broader context helps the student understand the problem and find missing knowledge that will ground experimental planning for the lesson. For this workshop, we framed the broader context in the use of road salt to lower the melting point of snow during the
wintertime, using this topic to introduce and discuss potential negative environmental effects while grounding the activity in a phenomenon that most people experience if they live in the Northern Midwest in the wintertime. We offered a science research question (e.g., “How does road salt affect the chemical composition of snow?”) to the teacher participants so that they could focus on experimental design over the course of the workshop to mirror what students would be asked to do. Teachers were then asked to build a hypothesis based on a map of the college campus and a database of samples that the designers collected around the campus. The bottom half of Figure 2.3, going from narrow to broad, shows how the results of an experimental plan get placed into the context in which the data was collected to create a narrative that describes how an experiment fits within a broader context.

During the second part of Day 1, the teachers selected samples based on their research question and hypothesis and used the Mohr method to analyze their samples. Once the teachers calculated the chloride concentration, they constructed models depicting how their results fit with the context of the locations of their collected samples. Teachers then presented their models and discussed how their results fit in with the broader context as presented earlier in the day, completing the research process. At the end of Day 1, teachers participated in a focus group where they reflected on the notes they took and their general impressions of the activity. Between Day 1 and Day 2, we asked teachers to consider changes they would make based on their students’ prior knowledge and curricular saliency.

The goal of Day 2 was to capture teachers’ structured adaptation and implementation of the curricular materials. Throughout the morning, teachers were asked to adapt the materials collaboratively. The designers were available to answer questions, offer advice, and discuss available resources while the teachers adapted the lesson. Teachers then taught the adapted curricular materials to a group of high school students. They participated in a focus group to discuss their impressions of the experience and student reactions to the specific adaptations. We then presented Figure 2.3 along with handouts with summaries of the SEPs to teachers to generate feedback on their perceptions of the framing materials and considerations we should make for future iterations.
2.4.5 Data Collection and Sources

Data for this analysis were collected throughout the two-day workshop and are summarized in Figure 2.2. We collected several forms of data to inform our analysis, including artifacts that the instructors completed and created, written reflections that occurred throughout the two days, video-recorded focus groups that occurred at the end of the two days, and video data of teachers interacting with and adapting curricular materials. Reflections were categorized as either informal or formal. Informal reflections consisted of teacher jottings of in-the-moment thoughts while teachers learned and adapted the curricular materials. We collected, copied, and returned the teachers’ reflections at the end of the workshop. Teachers reflected formally at the end of each workshop day using a private Google Document. A teacher’s document was shared between the teacher and the designers with guiding questions, capturing teachers’ perception of the day’s activities, their reflections about their learning as a participant in the workshop, and activities that they may or may not apply from the workshop (Table 2.3).

To learn more about teachers’ thoughts about the materials, we hosted two reflective focus group sessions at the end of each day. These sessions consisted of the three teacher participants, the clinical instructor from the school of education, and the two graduate students. These were audio and video recorded. The focus group sessions took around one hour to complete. The questions for the focus group differed between Day 1 and Day 2 depending on the activities completed during the day (see Table 2.4). The questions were semi-structured so that teachers could complete their thoughts and build on each other’s perspective. The Day 1 focus group centered on teachers’ specific thoughts about the lesson, how the lesson related to the SEPs, and the teaching practices that were present in the lesson. The Day 2 focus group involved

<table>
<thead>
<tr>
<th>Table 2.3. Reflective journal questions asked of participants at the end of each workshop day.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provide a brief descriptive reflection of the model teaching you experienced, including a synthesis of one or two important ideas you gained about teaching practices from reflecting on the model teaching. You should include examples observations of what you noticed for learning how to bring scientific and engineering practices into laboratory teaching to support your reflective writing and what you might be wondering about this lab.</td>
</tr>
<tr>
<td>Please provide insightful, or analytical reflections about your learning. Reflect on what you learned from participating in this model teaching experience and what you wonder about student learning of scientific and engineering practices.</td>
</tr>
<tr>
<td>What do you think you will and will not apply from this workshop? This section should include references to class activities, discussions, or readings to justify your current and future instructional choices in support of student learning.</td>
</tr>
</tbody>
</table>
teachers’ on how the students engaged with the activity, the research cycle (Figure 2.3) and how it related to the SEPs, and contextual considerations for their classroom.

There were three opportunities to capture teachers’ interactions with curricular materials throughout the workshop. The first opportunity was Day 1 of the workshop, when we introduced the teachers to the curricular materials as learners. During this time, we video recorded the initial presentation (3 hours) and the laboratory session (1.5 hours) to capture interactions between teachers and workshop facilitators, including clarifying questions of content, suggestions for

| Table 2.4. Participant focus group questions asked at the end of each day. |
| Day 1 Focus Group Question Examples |
| What did you think about the lesson overall? |
| • What were your learning experiences? |
| • What do you think your students would experience? |
| • What were your thoughts on experiencing environmental research as content? |
| • What types of materials would you need to make this work? |
| • How long do you think this lesson would take? |
| What do you think about the use of the NGSS Science and Engineering Practices? What practices did you notice? |
| Describe the practices in relation to: |
| • The instruction that you noticed |
| • Your own learning |
| • How they might be perceived by your own students |
| Let’s talk about the experience in relation to the research cycle diagram in figure 2.3 |
| • What do you notice about this figure? |
| • Does this capture what scientists do in the laboratory? Explain? |
| • How do the NGSS Science and Engineering Practices relate to this figure? |
| Describe what you noticed about the teaching practices you experienced? |
| • What worked well with this lesson? What changes might you suggest? |
| • How long do you think this would take? |
| • Could this be applied at your site? |
| Day 2 Focus Group Questions |
| Tell me how you think the activity went with the students. What did you notice? |
| • Describe examples of student engagement. |
| • Was there any other way that workshop facilitators (designers) could have better supported you in teaching the information in day 2? |
| What part of the activity stood out to you as the most useful in working with the research cycle (presented in Figure 3) |
| • In what ways did participating in the workshop influence your perspective on how scientists do their work? |
| Looking at the NGSS Science and Engineering Practices, which practices do you feel were addressed in the activity? |
| • Referring to the list, which practices do you think were not well-addressed in the activity? |
| What barriers exist in applying this lesson in your context? |
| • How would you adapt this material to overcome these barriers? |
adaptation, and comments about specific activities. The second opportunity occurred during the collaborative adaptation session on Day 2, when we video recorded the teachers as they adapted the curricular materials that they would present to the students (3 hours). This session produced artifacts where teachers adapted specific materials as a product of this collaboration. The final opportunity to capture teachers’ interactions with curricular materials happened when the teachers implemented their adapted curricular materials with the student volunteers (2 hours). This implementation was video recorded while we took field notes to capture salient instances to guide analysis. For instance, when teachers made an adaptation to a curricular material, we made note of the nature and cause of the adaptation, the discourse between teachers surrounding the adaptation process, and contextual features to guide further analysis.

2.4.6 Data Analysis

This study focuses on how teachers interpret the critical components of a lesson (Stains & Vickrey (2017) and instances of teacher sensemaking where teachers adapt curricular materials for their context (Allen & Penuel, 2014). All video data from the lessons and focus group were transcribed verbatim and analyzed using NVivo 12 (QSR International, 2018).

*Initial Deductive Coding.* To begin the data analysis, we deductively coded the data using selective coding (Saldaña, 2016). We identified instances where teachers mentioned the identified critical components of the workshop (e.g., environmental chemistry disciplinary practices, relevant problems, and NGSS SEPs). Using this approach, we coded the teacher reflection documents to learn how teachers interpreted and phrased the critical components. We used these interpretations and phrases to construct operational definitions of the critical components that we applied more broadly to the focus group and teacher adaptive collaboration session to refine and revise the operational definitions. For example, when a teacher mentioned that students communicating their results to an authentic audience could be a way to engage their students further, we labeled it as a representation of the SEP of *Obtaining, Evaluating, and Communicating Information.* At this point, the education research members of the design team established a consensus on the definitions of the critical component codes. They then applied the codes to the entire data set (Saldaña, 2016).

*Initial Inductive Coding.* We then inductively coded (Miles, Huberman, & Saldana, 2014; Saldaña, 2016) the data set for instances of teacher sensemaking (Allen & Penuel, 2014). To do
this, we read through the teacher reflection documents and focus group data searching for contextual factors that would ground further adaptation for curricular materials. When multiple teachers mentioned similar contextual factors, we grouped the codes and constructed an operational definition to guide further analysis. Continuing the example from the previous paragraph, when teachers mentioned that there might not be a way for students to present their findings in their classroom context authentically, we labeled the phrase as an institutional barrier. Once we established a codebook, we applied the codes to the rest of the data set and further refined the definitions through constant comparison (Nowell, Norris, White, & Moules, 2017; Strauss & Corbin, 1990).

Final Coding. While identifying the contextual factors that teachers mentioned, we noticed that teachers also suggested potential adaptations, which we labeled as negotiations (Windschitl, 2002). With the previous examples, the teachers recognized the tension between having students communicate their results to an authentic audience and their classroom context being unsupportive of the practice. The teachers then collaborated and suggested that they could hang posters throughout the school and invite environmental experts from the community to hear and offer feedback. After identifying this negotiation process as a course of adaptation, we coded the data set a third time and located other instances where this occurred. After completing the coding of the critical components, contextual factors, and negotiations, the codebook contained 44 independent codes.

Once we established the codebook and reached a consensus (Armstrong, Gosling, Weinman, & Marteau, 1997) in definitions for each code, we constructed a thematic diagram (Braun & Clarke, 2006) as a process to condense, recategorize, and visualize relationships between codes. To do this, researchers placed a code and its’ definition on a slip of paper. They organized the codes based on similarities and relationships on a whiteboard, taking time to discuss the placement of each code. This process produced clusters of related codes, which we labeled as categories. We named and defined each category by corroborating the definitions and examples associated with each code in the category through consensus. This diagram process reduced the number of codes to 26. We then applied the 26 categories to the artifacts, written reflections, video-recorded focus groups, and video-recorded presentations. A diagram depicting the different codes and a summary of the relationships between codes can be found in Supplemental Materials (Section 2.9).
2.4.7 Validity

Within this study, we operate under a constructivist paradigm of qualitative validity (Cian, 2021), to capture a nuanced and contextualized representation of the participants’ interaction with the workshop. We provide in-depth accounts of our methodology and results, recognizing that researcher bias is impossible to fully mitigate. Within this paradigm, we seek out and report all types of evidence, including that which may disconfirm our findings, so that readers can have a clear depiction of the phenomenon we study. While the workshop occurred over a two-day period and we collected extensive data, conversations with teacher continued for years after the event. In these conversations, we discussed our findings and asked for feedback on how we represented their experiences.

2.5 Results and Discussion

Upon the analysis of our research questions “How do users interpret the critical components of a curriculum?” and “What do users consider when adapting curricular materials to their context?” through the lens of our coding scheme, we found three distinct categories that could be used to explain teacher engagement within the workshop: Critical Components, Critical Knowledge, and Negotiation.

2.5.1 Critical Components – Relevance

We align our definition of relevance in science education with Stuckey et al. (2013), where science learning becomes relevant whenever learning will have positive consequences for the student’s life. In particular, the teachers focused on the vocational and societal dimensions of relevance in discussing the curricular materials. Teacher conversations of relevance provided examples of all four critical components (Table 2.5).

Vocational relevance concerns itself with offering students the opportunity to explore future professions and careers and how they relate to the students’ experiences and interests. For example, the teachers’ schools are situated in the same town as a major research university, and most of their students have heard that scientific research occurs in the laboratories but may not understand what happens within the research process. Jocelyn mentions in the Day 1 afternoon focus group, “Particularly for students, we're so close to the University and you're engaged in
this research here at the university. It creates the big-picture theme that I think is really relevant.”

The group then discusses that the collection and analysis of actual samples from actual research labs can model for students the research process that occurs in laboratories and universities. Johnny continues the conversation in the Day 1 focus group by adding,

*I think for a high school student, or even a middle school student, depending on the age, the fact that we're using actual samples means, “Hey, I'm just a high school student, and I'm helping out this bigger research effort.” ... And that is, helping students take their science learning and connecting it to the real world, so it's not just scientific knowledge, but it's scientific knowledge as a part of this bigger narrative about learning about research and our world.*

Johnny’s statement alludes to the procedural critical component that the simple act of being connected to a greater research effort is enough to frame the lesson in a way that engages students in his classroom. While this does not fully match the designers’ intent based off Stuckey et al. (2013), the teachers recognized a value in students learning about the science that is happening within their community. The above conversation also portrays an educative critical component where the teachers mentioned and discussed how learning about and engaging in a larger research effort models how scientific knowledge is generated and applied in the students’ community, which aligns with the designers’ thoughts about supporting teachers in this work.
The societal dimension of relevance develops the students’ understanding of the “interdependence and interaction of science and society, developing…competencies for contributing to society’s sustainable development” (Stuckey et al., 2013, p. 18). In this particular instance, we framed the curricular materials using a socio-scientific lens (Sadler, 2009), where the environmental impacts of the use of road salt guided the data collection process. This was best captured in a dialogue between teachers during Day 2 while collaborating to adapt the curricular materials:

David: I would say considering, in this specific example, the context would be thinking about the results we have—the context is their location. The context is the accuracy of the way we did things, just going back to where it came from. So, we started out talking about environmental impact, we're looking at snow samples in (our community), so it's considering our results within that context.

Jocelyn: Yeah, the context for me, I think, is putting those samples into broader categories of like...that's really lumping the field and the arboretum samples together when you talk about them...kind of. There's only one of them that you could lump into a different category...

Johnny: Right, right, right.

Jocelyn: ...and then that allows you to talk about these broader impacts, right? You're saying, “Oh, I'm interested in the grassy areas, I'm interested in the car infrastructure impacts,” which are taking those contextual results and bringing it out.

Johnny: So, it is something that you obviously did not measure or plan to measure, but it's a question that you're gonna raise.

David: Yeah, I think all of that goes into it. If you're going to analyze something, and you say, “these are the results,” you had to consider where they came from, how they were obtained and all of those decisions that went into the sampling.

Throughout this dialogue, the teachers discussed how geographical areas in the community could help categorize the data set to narrow the focus of their research question. By doing this, students would need to be mindful of where samples are generated and why those samples are important.

Johnny continued this in his written reflection from Day 2:

*Usually, my students investigate procedures (titration, gravimetric analysis) or properties (qualities or a mixture of powdered sugar and calcium carbonate, or properties of liquids) using samples which I generate. These samples are not necessarily connected to real, environmental or real-world conditions. The source of the samples is important in order to give the lab more scientific and actual societal applicability since the students can connect class material to spaces in their community.*
In this statement, Johnny recognizes that his normal classroom structure includes samples and experiments that are teacher-directed and disconnected from students’ everyday life. He mentions that having students determine the source of the samples allows students to explore scientifically how classroom content can connect to their greater societal context. These passages also capture how the teachers and students shift their traditional roles in the classroom to be co-participants in the research process, embodying both pedagogical and student engagement critical components as intended by the designer.

2.5.2 Critical Components – Science and Engineering Practices

The workshop embeds the SEPs (Table 2.1) as procedural and educative components, as they provide guidance on how teachers can embed practices in the classroom that resemble the work of scientists. Through teacher conversations, pedagogical and student engagement critical components were observed as well (Table 2.6). Presented herein are examples of where teachers discussed aspects of the SEPs as they were presented in the workshop. Specifically, we present the SEPs obtaining, evaluating, and communicating information in this discussion and asking

<table>
<thead>
<tr>
<th>Critical Component: Science and Engineering Practices</th>
<th>Designer Description</th>
<th>Teacher Discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedural</td>
<td>Providing structures to engage students in the authentic application of the Science and Engineering Practices</td>
<td>Using Whiteboarding to support argumentation and public communication of results</td>
</tr>
<tr>
<td>Educatve</td>
<td>Offering opportunities for teachers to learn how to apply the Science and Engineering Practices with the guidance of scientists</td>
<td>What teachers learned by participating in a whiteboarding session and how to apply this technique within their context</td>
</tr>
<tr>
<td>Pedagogical</td>
<td>Teachers facilitating discussions of their investigations and results using whiteboards instead of using more traditional methods</td>
<td>How whiteboarding can be a way to generate student discussions and provide each other feedback on their data and results</td>
</tr>
<tr>
<td>Student Engagement</td>
<td>Students presenting their findings and discussing patterns and trends that they may notice between sampling protocols</td>
<td>Students learning from each other and having multiple sources of feedback on their protocols and results</td>
</tr>
</tbody>
</table>

Table 2.6. Examples of the critical component of Science and Engineering Practice of Obtaining, Evaluating, and Communicating Information.
questions and defining problems, and planning and carrying out investigations in the Supplemental Material.

Obtaining, evaluating, and communicating information is defined as students “being able to read, interpret, and produce scientific and technical text...as is the ability to communicate clearly and persuasively” (NGSS Lead States, 2013, p. Appendix F). Scientists use multiple pieces of information to evaluate the merit and validity of claims. Likewise, within the classroom, students use this practice both verbally and orally, to communicate information, evidence, and ideas using tools, such as tables, diagrams, models, and graphs. Within our activity, students can use this practice through an informal whiteboarding session. In this session, the teacher asks students to present their research question, summarize their findings graphically and orally, and list next steps and implications after they conclude the experiment. After their answer on the whiteboard is written, students present their findings to the group and solicit feedback from each other to inform the next iteration of their experiment. Concerning the white boarding process, Jocelyn mentions in the Day 1 focus group:

Another thing I think was very important in the analysis is that we did it publicly. Because what I do with my students when we get finished, they write a lab report. While I'm the only one who reads the lab report, but there might be something else that another group learned. And if they're not saying their conclusion, then nobody but me is learning that conclusion and then even the kid writing that, maybe a great statement, doesn't realize how significant that statement is until someone else goes, "Oh wow, that's really cool." So, I think the public presentation is very important.

In this passage, Jocelyn contrasts her normal practice of having students communicate in the classroom through lab reports with how information is presented with whiteboards in this workshop. She recognizes that the audience is narrow when students produce a lab report at the end of an experiment and that her students may find value in presenting their results publicly. She also mentions that making public presentations allows students to learn from each other’s results and approximate the significance of their findings. Johnny affirms how the structure helps students learn from each other in the Day 2 focus group by saying:

I think it's things like [the whiteboarding activity] is what I felt like we get when you have the whole class sharing. Maybe the students don't necessarily pick up on that, but we definitely pick up on that. "Wow, I didn't even know." That's a take-away of mine from that sharing time yesterday, and like, "Wait a minute, somebody else might say something." That's how I thought about with the lab reports too, that it's just an
individual lab report versus a group sharing thing. It can be very powerful in terms of what I think also happens in research.

Johnny adds that reactions between students while information is orally presented can be used to refine students’ ideas about the implications and next steps of their experiments. He related this to the practice of scientists during the research process. In this instance, both Jocelyn and Johnny are considering pedagogical and student engagement critical components of this SEP as intended by the designer.

Not all SEPs were successfully represented within the snow chemistry activity. For instance, David points out in the day 1 focus group: “I thought the planning and carrying out investigations was more alluded to in the introductory discussion, but realistically, there were very few things that we planned in terms of what we did today.” Due to the time constraints of the workshop, facilitators presented samples to the teachers and the experimental protocol for the titration that they used to analyze the samples. With his statement, David alluded to the open-ended practice of planning and carrying out investigations, where students design experimental protocols that generate data based on their initial hypotheses. David also recognized these constraints in his Day 1 written reflection:

I did enjoy that there were attempts to think about how the entire process of planning and carrying out an investigation. This is hard to accomplish at times especially since the lab work, a titration is such a small part of the process.

2.5.3 Critical Components – Disciplinary Practices

Scientific researchers belong to disciplinary communities that construct knowledge in a socially supported manner. For instance, disciplinary scientific literature conveys the values, expectations, and norms of a scientist’s community which inspire researchers to use tools, experimental protocols, and analysis methods to construct new knowledge (Sandoval, 2005; Spencer, Dershimer, & Shultz). In a similar light, disciplinary practices in the classroom seek to mimic the knowledge construction of scientists from the perspective of specific disciplines (Ford, 2008; Ford & Forman, 2006). This activity focuses on introducing disciplinary practices related to snow chemistry at the workshop. The procedural and educative critical components are present in teacher discussions, whereas pedagogical and student engagement are discussed and critiqued by the teachers (Table 2.7).
The tools used by snow chemists in practice are prohibitively expensive to use in high school classrooms, but the Mohr method can offer a similar analysis to generate data that grounds discussion similar to the knowledge production of snow chemists (Ibanez et al., 2008; May et al., 2018). For instance, students use the Mohr method to analyze chloride samples that they collect, find patterns within the data, and make claims based on data that other students can critique. This is a procedural critical component. The teachers in the workshop noticed this, with Johnny mentioning in the Day 1 afternoon focus group:

*I think that is a real core piece -- whenever you try to give students real world experience, and sometimes I'm like, "I have no idea how I would test it." It's like: you gotta fix this thing in your house, but you don't know they have a tool to do that and it's like, "They have a tool to do that? Well, it's easy now." So, once you know the tool is available, then it becomes much easier.*

In this statement, Johnny mentions that he tried to bring in real-world experiences, only to have difficulty in knowing ways to collect and analyze data, as he was not trained as a snow chemist.

This embodies the educative critical component, where teachers learn an analytical technique to bring back to their classroom. However, a large part of their discussion extended the educative critical component to focus on where this method would fall within their overall curriculum (Supplemental Material).
During their experience with an activity designed to simulate disciplinary practices in science, teachers noticed a tension between modeling scientific practice and actively participating in scientific practices. For example, David mentions in the Day 1 focus group:

*What we were doing wasn't research. We might be simulating research in some way, and so if we go back and take this into our classrooms, there's a difference in how we would have to frame it. When [the science graduate student] speaks about it, he can say “we” and talk about that a lot because he is doing that work. From our perspective, that narrative would have to be “If we were doing this type of research, what sort of decisions would we make? These are the types of decisions that scientists are making and we can tie this into what we're thinking and how they go about doing this work.” We would still have the research background and the narrative, but it certainly wouldn't be our work.*

David makes an important point by asking the question “who is doing the science?” and discusses how the framing differs depending on who is participating in the activity. For instance, David recognizes that the science graduate student on the design team actively conducts scientific research, participating fully in their discipline’s knowledge construction process. Teachers, on the other hand, must prompt their students to think as scientists to make their decisions. By making this distinction, David calls into question the authenticity of disciplinary practices in their classroom.

### 2.5.4 Critical Knowledge

We define critical knowledge as the specific, contextualized knowledge that workshop participants possess that are important to the implementation of a curriculum or practice in the classroom. These critical knowledge components are the results of the inductive analysis outlined in the Methods section, focusing on contextualized teacher responses to the critical components during the workshop. This analysis yielded 6 categories of critical knowledge. Three of the categories focus on the teacher’s students: Student Background, Student Difficulties, and Responses to Student Difficulties. The other three focus on the teacher as an individual: Professional Beliefs, Institutional Barriers, and Consideration of Techniques from Workshop. In this section, we unpack Student Difficulties, Institutional Context, and Professional Beliefs, to provide examples of how teachers consider their context while engaging in workshop materials. Full definitions and examples of each category can be found in Table 2.8.
2.5.5 Critical Knowledge – Students

Much of the discussion depicting critical knowledge surround teachers’ perception of how students would interact with the material presented in the workshop. This differs between school contexts, student demographics, and teachers’ perception of the curriculum prior to the course. One example of student difficulties includes how comfortable students are with problem solving in math. For students to engage in titration as a tool, they need to carry an understanding on how to gather data to find the endpoint and analyze the data to find a concentration. To account for this, the workshop design team made a pre-calculation activity to help the students work through the math. Teachers performed the pre-calculation activity, titration, and data analysis during the experimental portion of Day 1. Afterwards, during the Day 1 focus group, Jocelyn points out:

One of the things that happens, depending on how many pre-calculation students have done, is that I can see students getting lost in the calculations and that's where they have a lot of trouble, and then you never get to the conclusions.

In this moment, Jocelyn speaks from her experience that many students focus on the math and struggle to accomplish the goals of the lab experience. She continues in her Day 1 reflection, “This was sufficient for someone who has worked with these types of calculations. I don’t think this would be enough for a novice.” In doing this, she recognizes a difference between contexts, and that the activity assumed a base familiarity with the concept of titration. Jocelyn identifies a potential area of adaptation that related to her students, which contributes to a contextualized perspective of the student engagement critical component of the activity.

Another student difficulty that the teachers mention throughout the workshop surrounds the challenges of keeping students focused on the scientific process. We designed the workshop to have students explore the context of the experiment through literature, but teachers note that this activity might not provide enough guidance to help students build a hypothesis. The teachers discuss this in the Day 2 collaboration session:

Jocelyn: What happens if they totally fumble on the hypothesis?
Johnny: Then I've got to think that when they analyze the data within a context, they'll realize they didn't answer their question.
David: That'd be the equivalent of a grad student going in without any of the having to go to the lab and then realizing after they get data, "Oh, crap. I had no idea what I was doing from the very beginning. How could this have happened?" You know what I mean?
Jocelyn: *So just let them write whatever they write?*

David: *Let's just hope 80% of people give good hypothesis, not 80% give a bad hypothesis. That would be interesting.*

The participants identify that hypothesis-building and collecting data with a limited understanding for the context of the work could be a potential problem. The conversation shifts to consider missing data because of errant hypotheses and research questions:

*Table 2.8. Definitions and examples of critical knowledge categories.*

<table>
<thead>
<tr>
<th>Critical Knowledge</th>
<th>Definitions</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Teacher</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Professional Beliefs</td>
<td>Teacher perspectives of their professional roles and responsibilities</td>
<td>• Specific beliefs on how teaching and learning occurs in the classroom</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Thoughts on what is expected of teachers in their professional context</td>
</tr>
<tr>
<td>Institutional Barriers</td>
<td>Specific information relating to a teachers’ classroom context</td>
<td>• Classroom structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Number of students</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Administrative focal points within their building</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Science curriculum of the department</td>
</tr>
<tr>
<td>Techniques from Workshop</td>
<td>Teachers’ thoughts on specific activities relating to the workshop</td>
<td>• Perspectives on how the workshop activities can be used in their context</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Thoughts on where the content material of the workshop fits into the science curriculum o the department</td>
</tr>
<tr>
<td><strong>Student</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student Background</td>
<td>Teachers’ perspectives of the students that they teach</td>
<td>• Diversity and background understanding of their students</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Perceptions of what their students ‘can and cannot do’</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Understanding on how their students perform on specific subjects</td>
</tr>
<tr>
<td>Student Difficulties</td>
<td>Teachers’ thoughts on difficulties the students encounter while learning science</td>
<td>• Ways in which students struggle with mathematical topics in the classroom</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Difficulty in seeing change in color for the endpoint</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Culture of ‘getting the right answer’ in higher-level classes</td>
</tr>
<tr>
<td>Responses to Student</td>
<td>Teachers’ thoughts on how they help students overcome identified difficulties</td>
<td>• Contextualized perspectives on how instructors respond to specific student difficulties.</td>
</tr>
</tbody>
</table>
Jocelyn: I think one of the things that's very challenging for students who don't get data is to know that they don't have a bad grade because they don't have data. Because usually if you're doing a lab and you're not getting the expected answer, or whatever is perceived as the right answer, then students are very anxious about that.

Johnny: It's not so cut and dry. Sometimes, in science, you're going to spend a whole year working on your instrument before you can get any data, so ... dealing with that, well I couldn't get any results or gosh, my titrations I couldn't figure out how to determine the endpoint...So I think that you have to help students understand that, especially students who are in AP classes, they're used to getting the right answer. And now, it's not so obvious. In some ways, that might be risk-taking kind of thing, but...they're expecting certain results, they're expecting a certain number, and they are going to get to their first titration, and they are going to go, “What did you get? How much did you get?” They want to know how their number compares to the person next to them!

This passage reveals that the teachers are actively considering how the student engagement critical components embedded within the SEPs and Snow Chemistry Disciplinary practices relate to the culture of their classrooms. They posit that higher-level secondary students would struggle with generating hypotheses that have open-ended solutions and that their prior success in the sciences leading up to the activity conditions them to compare results and look for the “correct answer.” This concern alludes to a greater contextual concern with respect to students — that the culture of science in their classrooms, and the education system, makes it more challenging to introduce activities that resemble scientific research to their students.

### 2.5.6 Critical Knowledge – Teacher

As teachers learn a curriculum or practice in a professional development scenario, they consider contextual factors that affect transfer and implementation into their classroom. Institutional barriers expand upon the dynamics that affect the teacher because of the structure of their workplace. We saw many characteristics of institutional knowledge, including administrative initiatives, physical classroom limitations, and collegial interactions outside of the classroom. Extending the discussion above on the disciplinary practices educative critical component, how a school structures their overall curriculum for their science department could impact what a teacher considers feasible, even if they align with the material from a workshop. In the Day 1 afternoon focus group, Jocelyn mentions:
Jocelyn: *For me, our year-long junior Chemistry class...is now a sophomore, one-semester course, and for junior year, we still have to figure out what we're going to offer. I can't see me getting to titration or doing this [activity] with sophomores within one semester. Maybe with the AP kids?*

Johnny: *For the sophomores, because you just don't necessarily cover the material?*

Jocelyn: *Correct.*

The conversation continues with each teacher discussing where titration appears in their 4-year curriculum and how the material they learned in the workshop could be integrated. In this instance, Jocelyn identifies that titration is a topic that she covers with her advanced students and that this research activity would not apply to many of her students since it is not covered in the lower-level curriculum. Even if a teacher would be interested in implementing material from this workshop, coverage of titration could be limited in their context, posing a significant barrier that would impede fidelity at the procedural critical component. Similarly, timing constraints could differ between the workshop and the teachers’ schools, posing another potential limiter associated with the procedural critical component. David and Johnny, coming from the same school, discussed this in the Day 1 afternoon focus group:

David: *Listen, we have a distinct disadvantage because the labs that we do are very carefully constructed so that you get probably good data within, you know, those 45 minutes to an hour. But that's not the way the real world is.*

Johnny: *I think it actually would take me three, 45-minute periods, and maybe...we would start with a discussion, like the pre-lab leading up to the actual lab, and then we'd take at least a period to conduct the lab, and then we'd have to have a period for post-lab. And that whole post-lab period wouldn't have to be students making presentations; it could be they would work in their lab groups, maybe do some calculations, and come up with their whiteboard.*

In this conversation, Johnny and David pointed out that the duration of class periods in their context differs from how we structured the implementation activity in the workshop. David mentions that the structure of class periods creates a situation where they try to find activities that produce good data within their timing structure, which contrasts with how the scientific community operates. Johnny then brainstormed how activities from the workshop could fit into their school structure over the course of three days. As a result, both participants must consider how the workshop materials could fit into their school’s classroom period structure if they choose to apply the material.
The next example of critical knowledge is the professional beliefs of the teacher. This category spans many of the characteristics that influence what gets taught in the classroom, including educational experience, teaching experience, and beliefs about teaching and learning. For instance, science teachers often represent scientific practices without having direct experience in how scientists produce knowledge (Anderson, 2007; Capps & Crawford, 2013). As a result, teachers may not have knowledge of the specific tools required to implement the scientific practices that drive students’ classroom projects. A fuller picture of Johnny’s comment in the critical component section captures this tension in the Day 1 focus group:

Well, I'll tell you an example from our 7th-grade class: we study a stream behind our school, and we look up what experts study about water quality, and one of those things is how many nitrates and how many phosphates are in the water. And I was thinking, "Oh my gosh, how am I gonna figure that out?" Well, we do it by conductivity. Well, okay, that's not specific to nitrates and phosphates...I think that is a real core piece because whenever you try to give students real-world experience...but I'm like, "I have no idea how I would test it." It's kinda like how you gotta fix this thing in your house, but you don't know they have a tool to do that. And it's like, "They have a tool to do that? Well, it's easy now." So, once you know the tool is available, then all of a sudden, it becomes much easier.

In this instance, Johnny discusses that possessing knowledge of tools that scientists use to study specific questions could help them represent the processes of science in their classroom, which relates to the educative critical component. This encouraged a greater conversation on how research activities are often framed in the classroom, with David mentioning in the same conversation:

There is a ‘we vs. they’ thing in effect here. [The graduate student] could say “we” throughout because [he] was talking about his research. In a high school setting, I would frame this less as “what would ‘we’ do?” and more like “Here’s what ‘they’ really did.

David’s statement summarizes an important finding: while we constructed a workshop that represented SEPs through the application of snow chemistry disciplinary practices, the teachers were outsiders left to mimic the scientific process as depicted by the experts in the workshop. With our framing of the disciplinary activities, the teachers could only engage peripherally with the procedural and educative critical components because they did not have experience constructing knowledge in this field. This limited the tools teachers could use to lead research-type activities in the classroom and how teachers could function as agents in the research process. In his Day 2 reflection, Johnny notes:
I realized that placing a particular lab activity in a broader research context may not be easy for some teachers. It is difficult for teachers in the classroom not involved in any kind of scientific research to know of a greater research context for a lab.

2.5.7 Negotiation

In the previous two sections, we explored how teachers consider the critical components of a unit and use their critical knowledge to think about how the lesson relates to their specific context. The examples demonstrate that teachers are aware of what designers see as important aspects of a curriculum or practice and possess contextual expertise that could inform how a program overcomes potential barriers to implementation (i.e., moderating variables). Throughout the workshop, teachers tried to reconcile the designers’ intent behind the critical components with specific characteristics of their classroom, which we label the negotiation. Table 2.9 contains a summary of the critical components as the designer and teacher intended, critical knowledge mentioned by the teacher, and negotiations made by the teacher team for all critical components represented in Stains & Vickrey (2016) (Figure 2.1).

Within the workshop, we noticed that negotiation contained an acknowledgment of the critical component and a description of critical knowledge that would be crucial to the implementation. For instance, after the initial whiteboarding session on the first day, where teachers presented their data and discussed their results, embodying the SEPs described in the critical component section, David and Johnny mentioned the time constraints of their school context, as described in the critical knowledge section. In other words: they acknowledge the value in communicating their results to their peers but saw the length of their class period as a limiting factor. Discussing this further in the Day 1 focus group, the teachers began brainstorming ideas on how to overcome this constraint. As an alternative to the whiteboarding session, Jocelyn mentions, “If you walk through these halls, you'll see research posters hanging everywhere.” David extends this idea to consider his context by saying, “We have tons of bulletin boards throughout the halls where, if we had a project like this, we could put the results up for the rest of the school to see.” The teachers and designers then consider how the activity can be adapted for Johnny’s context while aligning to the procedural critical component, thinking about structures that allow students to engage in argumentation in asynchronous ways (e.g., gallery walk with posters, inviting experts from the community). This dialogue occurred
throughout the workshop wherever we gave teachers space to discuss and collaborate on the workshop materials.

Another example of teachers using negotiation relates to the educative critical component of disciplinary practices and teachers recognizing a limitation in their understanding of the research process. At multiple points throughout Day 1, David mentioned that the activity was a simulation of research and teachers were outsiders to the research process, especially considering the background of the graduate student and professor engaging in the workshop. During the Day 2 collaboration session, the teachers spent considerable time working through how to model the research. In this part of the collaboration, the teachers considered how they could frame the lesson to help students understand the context:

Jocelyn:  *I don't know, maybe we're doing a little individual research on what are the environmental effects of salting our roads. We do it so we don't slide around in our cars, but are we paying a price for that?*

David:  *I don't know that I'm really able to explain what I'm thinking, it's just that this is always going to be the hardest part for any of my classes—because they're not working within the context. I'm not saying we're not building a broader context within this [activity], because we are, and I think this is what you have to do to try and add that context.*

Johnny:  *When we talk about authentic, this is not authentic in the sense that researchers are working every single day in the field and thinking every single day about the context. It's just a little different.*

David:  *I think reflecting on the research process, I don't think first-year graduate students walk in and are like, "Yes, I'm super excited about salt." It takes years to get that. So, in a lot of ways, there's an insertion process that happens where reading lit reviews upon lit reviews upon lit reviews finally gets you to what your authentic product's going to look like, and something like that would take a lot of time.*

In this passage, teachers clarify their understanding of the difficulty in setting the context of scientific research practices in the classroom. They recognize that it takes years for scientists themselves to understand the broader context of their work and that it would be difficult to construct an educative experience for teachers to overcome the differences in training. Considering we designed this activity to explore the context in the length of a laboratory session (~2 hours), the teachers wonder how the context could be set without taking too much time. Continuing the conversation:
Jocelyn: So, we try and model it by introducing the broader context at the beginning, and our applications and our impacts are certainly going to have serious, serious limitations.

David: I think that's the hardest part because we talk about the broader context and researchers understand the broader context, but students doing a lab like this aren't immersed in that environment. When we talk about 'authentic' science from 'authentic' research that's the least 'authentic' part of it because they haven't been immersed in that world to be thinking about this type of stuff every day. And so, in lab today, if we asked them to connect to broader impact, that's artificial as well. When we know we can make claims about anything; we know the validity of those claims aren't very strong when we took three samples from one location. So that's not very broad.

Johnny: In general, they will have been in there for two hours. Their knowledge of the context can't be very strong. So that is where reading the articles could come into play. You usually have a lot of these articles and have students write two or three paragraphs about it.

In this passage, the teachers began thinking about ways to frame the lesson to engage students in thinking about the broader context. Jocelyn brings up introducing the broader context at the beginning and recognizing that the implications of the lab will have serious limitations. David builds on Jocelyn’s idea by recognizing that using the term “authentic” in these settings is ineffective, fleshing out that the validity of claims is inherently limited by sample size. Johnny then proposes using literature to connect their experiments to a broader context. During the afternoon activity, they limit the use of the term “authentic” and spend time having students connect their results to literature recommended by the graduate student and science professor. While a disconnect continued to exist between what “authentic” science practice looks like in the laboratory and the classroom, the teachers negotiated with the design team on how they could adapt the material in the space offered in the workshop while honoring the procedural critical component.

2.6 Implications for the Design Process

In this study, we set out to document and analyze the ways in which teachers interact with and adapt the critical components of a curriculum with the guiding research questions “How do teachers interpret the critical components of a curriculum?” and “What do teachers consider
Table 2.9. Examples of how teachers negotiated their interpretation of the designers’ critical component with their critical knowledge.

<table>
<thead>
<tr>
<th>Critical Component as laid out in Figure 2.1</th>
<th>Critical Component as designer intended</th>
<th>Critical Component as interpreted by the teacher</th>
<th>Critical Knowledge mentioned by the teacher</th>
<th>Negotiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedural</td>
<td>SEP of argumentation: whiteboards are used to display patterns and trends in data amongst students</td>
<td>Using whiteboarding as a mechanism to structure discussion of data amongst students in a public fashion</td>
<td>The time structure in class might hinder the depth of discussion in a whiteboard session</td>
<td>Allow students to create posters and use bulletin boards to display results between classes</td>
</tr>
<tr>
<td>Educative</td>
<td>Disciplinary Practices: The workshop covered information at the beginning of the lesson relating to literature on the environmental chemistry problem</td>
<td>Discussed the importance of the broader context and relating the material to the real-world examples in students’ lives</td>
<td>Teachers need more time and connections to research experts to learn about the broader context of the activity</td>
<td>Work with professors and graduate students present in the workshop to construct a literature review activity for students</td>
</tr>
<tr>
<td>Pedagogical</td>
<td>Relevance: doing a research project that relates to work that scientists are doing in their community</td>
<td>Doing a research project that relates to work that scientists are doing in their community</td>
<td>Needing direction on what types of questions to be asking and tools they could use to analyze that data students collect</td>
<td>Using disciplinary experts in the workshop to consider questions that could be asked; connecting teachers to scientists to conduct similar work</td>
</tr>
<tr>
<td>Student Engagement</td>
<td>Disciplinary Practices: students will construct a hypothesis based on where they collected their data</td>
<td>Students are building hypothesis related to a greater research project</td>
<td>Students will struggle with the open-ended nature of a research project and will need guidance</td>
<td>Talk to the students how this type of thinking may be different than what they experience in other science classes; create discussion groups about their hypotheses to generate feedback</td>
</tr>
</tbody>
</table>
Figure 2.4. Expanded Fidelity of Implementation Framework, including designers’ critical components, participants’ critical knowledge, and a space of negotiation where participants and designers adapt materials for participants’ structures. Within each of the critical knowledge section, a reflective question is included to guide the reader in learning about their participants.
when adapting curricular materials to their context?” While we captured evidence exploring both research questions in the results, we find that the teachers’ interpretation of the critical components occurred in tandem with their considerations for adaptation in their context; they could not be separated. During this workshop, teachers inherently viewed the critical components within the lens of their teaching context. They were eager to use their contextual expertise to adapt material with the designers in the space provided in the workshop.

2.6.1 Considerations for the FOI Framework

Considering the relationship between critical components and adaptation, we think it is essential to recognize the limitations of designing curricular materials and measuring their efficacy solely from the designer’s perspective. Workshop participants operate as individuals functioning in a greater social structure (Allen & Penuel, 2014, p. 137). They regularly adapt their teaching practices based on expectations placed upon them, their teaching beliefs, and the nature of their students. These moderating variables are impeding factors that affect how critical components transfer to participants’ teaching environments (Stains & Vickrey, 2017). Rather than viewing moderating variables as something to be studied externally by the designer, accounting for the adaptation process within the FOI framework is necessary to ensure participants adapt curricular materials without compromising the critical components (Figure 2.4).

Within this extended FOI framework, we propose shifting the labeling of moderating variables to critical knowledge and adapting our (the designer’s) language to account for the contextual expertise of the teaching professionals participating in our workshops. By doing this, we recognize and affirm that participants possess knowledge important to help an innovation transfer to practice specific to their experiences as professionals. Similar to the FOI framework, this critical knowledge can be split into two mirroring categories of structural and instructional knowledge.

We define structural knowledge as the knowledge the participants possess of their teaching context and background that could affect how they adapt a curriculum or practice. We split structural knowledge into procedural and educative, with a major difference from the critical component analog being that the designers’ understanding of a participant’s context is learned from the participant and not assumed or projected. Procedural knowledge is concerned
with understanding the participants’ teaching context. Within our workshop, this included understanding physical considerations of the teachers’ classroom structure (e.g., number of students, class schedule, period length, available resources), professional consideration of the teachers’ context (e.g., administrative initiatives, state and national standards), and focal points of the teachers’ departments (e.g., how to apply the SEPs). Educative knowledge considers the participants’ background understanding and knowledge of the subject. Our workshop included their background experiences with the subject (e.g., prior research experience, formal learning experiences).

Instructional knowledge is the knowledge participants possess of their classroom structure and the students that they teach. We split structural knowledge into pedagogical and student engagement, with adaptations to critical components being informed by the participants’ perspective of their role and their students’ role instead of expectations being placed on them by the designer. Pedagogical knowledge focuses on the individual teacher’s beliefs about teaching science and how they structure their classroom. Our workshop included teacher beliefs around a subject (e.g., the role of math in science) and thoughts about how to communicate findings (e.g., lab reports). Student engagement instructional knowledge concerns the participant’s perception of how students within their classroom would perform and interact with the innovation. Our workshop included students’ perceptions of success (e.g., making mistakes) and students’ thoughts about math (e.g., focusing on math instead of the science practices).

While designers can gain a general understanding of structural and instructional critical knowledge through peer-reviewed literature, consulting with experts, and qualitative research, it is also important to recognize the unique characteristics of the contexts in which our participants function. To encourage specific adaptations related to participants’ critical knowledge, we propose a series of questions that designers should use to learn from their participants (Figure 2.4). Within our workshop, we learned about participants’ critical knowledge through intentional structures, such as focus groups and a collaboration session, as well as through informal conversations and interactions. While we placed no expectation on teachers to implement the workshop materials within their context, we utilized their perspectives and this approach to adapt curricular materials in subsequent implementations (May et al., 2018; Spencer et al., 2021).
2.6.2 Relegating Power

From within this workshop structure, all stakeholders noticed a balancing of power (Esmonde & Booker, 2016) where designers recognized participants' expertise. David mentions in the Day 2 focus group:

*One of the other things about being here, about this type of workshop, versus a lot of the others ... There's a give and take. It's really interesting to watch, from a teacher's side of it, that you all have been interested in what we were doing and seeing how we go about doing things, just as we were interested in watching you and thinking about what you're doing at the university. It was nice to see both sides of that.*

We found the structures we implemented to help us understand how teachers engaged in teacher sensemaking (e.g., focus group, embedded collaborative time) created a collaborative environment where participants learned how to sustain critical components under the designers’ guidance while adapting the curricular material using their critical knowledge. By doing this, we simultaneously recognized our own limitations in perspective as designers while affirming our participants' professional and contextual expertise. We label this collaborative environment the *space of negotiation* (Figure 2.4), where active reconciliation occurred between the designers’ expectations and participants’ contextual knowledge.

While we affirm that issues in curriculum transfer could be related to “improper implementation of the EBIP, [and] not the EBIP itself” (Stains & Vickrey, 2017, p. 2), we think this issue could be productively reframed to account for the adaptation that occurs as a participant considers implementing *from within their teaching context*. In this particular workshop, we included spaces where the teachers discussed the critical components and their teaching context with other participants and the designers. We noticed that the teachers used these spaces to problem-solve, troubleshoot, and adapt with the designers present to ensure that the adaptations properly represent critical components. Structures where teachers inform the design and implementation process are well-reported in education literature. For instance, Participatory Design Research (Bang & Vossoughi, 2016) and Design-Based Implementation Research (Penuel & Fishman, 2012) call attention to power dynamics from within the curriculum transfer process and leverage the contextual expertise of participants to shift their designs and aid in implementation after the initial workshop. These collaborative design methods (Penuel et al., 2020) also recommend prolonged engagement with participants to provide iterative support for
lasting change from within participants’ structures. The findings from this workshop and the aforementioned design structures informed the development of an environmental chemistry module with a Tribal College in northern Alaska, where the authors partnered with faculty and community members to explore culturally relevant design (Spencer et al., 2021). Other programs that employ similar methods with teachers include the POGIL (process-oriented guided inquiry learning) project (Moog & Spencer, 2008; POGIL, 2021), American Modeling Teachers Association (AMTA, 2021; Jackson, Dukerich, & Hestenes, 2008), Biological Sciences Curriculum Study (BSCS, 2021), and the Knowles Teacher Initiative (Knowles, 2021).

2.7 Conclusion

Concerning the results of this specific workshop, we wonder whether characterizing and measuring FOI without considering adaptation due to participant context is a realistic construct. If adaptation based on context is an accepted and normal consideration for participants, then we should expect that the nature of the critical components could shift as participants implement new techniques, especially if the designer does not build collaborative structures to consider the critical knowledge of participants and negotiations that they may make (Figure 2.4). Thus, we advocate for prolonged and collaborative engagement with participants as they implement a curriculum or practice if we aim to have our designs transfer to practice. In doing this, we can understand the specific, contextualized experiences of the professionals in our workshops and partner to ensure the applicability of EBIPs.

2.8 Acknowledgements

We would like to thank Prof. Kerri Pratt, Nathaniel May, and Alexa Watson for their contribution in designing the curricular materials for the workshop. We also recognize the teachers and students who participated in this workshop during their summer break. We are sincerely grateful to Leah Bricker for providing insight on frameworks related to this manuscript and deep questioning necessary to drive our data analysis forward. We also thank Megan Connor for leading a part of the implementation during the workshop. We acknowledge Kathryn Hosbein, Amber Dood, Ina Zaimi, Rebecca Fantone, and Danielle Maxwell for their contributions in refining our perspectives during all parts of the analysis and writing process.
2.9 Supplemental Materials

2.9.1 Expert Consultation

During the design process, we consulted experts on the design team to capture their perspective on the motivation behind the activities included in the lesson and if they aligned with our empirical research framing. This took the form of informal conversations during planning and implementation of the workshop and a formal interview after the workshop. The formal interview was semi-structured and included questions, such as: “What led you to design the lesson?” and “What are the most important aspects of the lesson for students to grasp?” The interviews corroborated the empirical research presented above. For instance, the graduate student on the design team mentioned in an interview:

Yes, you could look at all the samples, or you could look at just five of them. But that's up to you. And I can tell you, guide you, and help you reduce some of those samples. I think a lot of the work with planning and carrying on investigations on our role [as instructors] is reducing failures. Because...failure is a part of research, but I think this idea...almost like a research bootcamp where you've got to fail, and fail, and fail, and then you can...get amazing samples to work with, amazing deterrents...and then you're going to figure it out. And you're going to plan it out based on your results, picking good things to look at, and you're going to have some sort of research question idea in there...and so it's kind of like confronting the unknown.

This statement characterized the role of the instructor as facilitator, helping guide students through the research design process through reducing failure and leading students through the implications of their experiments. The critical component represents the SEPs of Planning and Carrying out Investigations and Analyzing and Interpreting Data by calling for students to iteratively develop their research questions and experimental protocols through quickly assessing data. Finally, the statement reveals that learning from previous failures is an important characteristic of a disciplinary practice in his field.

2.9.2 Coding Scheme

This section is divided into four subsections providing details of the coding process applied to the data set: initial deductive coding of the critical components, initial inductive coding of critical knowledge, final inductive coding of the space of negotiation, and collapsing the codes. It
is important to note that the figures 2.1, 2.2, and 2.3 show the final diagrams depicting relationships between codes after they were collapsed in the consensus activity.

2.9.3 Initial Deductive Coding: Critical Components

The data was initially coded looking for critical components as laid out in the Fidelity of Implementation framework. Figure 2.5 lays out how the authors conceptualized the codes for critical components (blue). The top relationship between teachers and students depicts the role of teachers engaging in reflective practices as if they were students. The middle components depict the relationships between the three primary critical components, relevance, SEPs, and Disciplinary Practices. The bottom triangle captures the teacher conversations about the workshop and considering more specific parts of the critical components. Table 2.10 shows examples of some critical component categories as they were mentioned by the teachers.

![Critical Components Diagram](image)

**Figure 2.5.** Thematic Sketch of the critical components after initial deductive coding using the Stains and Vickrey (2017) framework. Critical components are in blue, with greater themes being denoted in darker colors.
Table 2.10. Example critical component codes from initial deductive coding.

<table>
<thead>
<tr>
<th>Category</th>
<th>Example Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevance</td>
<td>“It looked like a legitimate research sample, but I guess it was not a legitimate research sample. So, just going through that process and the fact that it's not just a titration with solutions that were just made up… It creates the big picture theme that I think is really relevant.”</td>
</tr>
<tr>
<td>Relevance and SEPs</td>
<td>“I think there's a specific narrative connected to what you're researching, like the chloride concentration in snow in different places as part of migration… but there's also the narrative how we do science and the questions that we ask.”</td>
</tr>
<tr>
<td>In the Moment Decisions</td>
<td>“Having enough time is always tricky with these labs, especially the first time through them. We adjusted by some direct guidance of students. We also did not require the students to calculate the concentration of the chloride ions in the samples.”</td>
</tr>
<tr>
<td>Teacher in Role of Student</td>
<td>“I think that it was good for me to experience problems that students may encounter. It gives me a better idea of what they are experiencing as the ‘learner.'”</td>
</tr>
</tbody>
</table>

2.9.4 Initial Inductive Coding: Critical Knowledge

While critical components were coded (blue), teachers’ made comments based on specific, contextualized information from their teaching sites, which we labeled as critical knowledge (green). Figure 2.6 depicts critical knowledge surrounding the critical components, as everything in the workshop was critiqued based on the teacher contexts and classrooms. We coded critical knowledge under two categories: teacher and student. The teacher category focused on teacher-specific information, such as beliefs on teaching and learning and techniques they resonated with from the workshop. The student category focused on teacher impressions of how students would react to the material, such as student difficulties with the content area. Examples codes of these categories can be found in Table 2.11.
2.9.5 Final Coding: Critical Knowledge

We noticed that teachers paired many of these critical knowledge codes with negotiation phrases that related to a critical component, which we labeled as negotiations (orange). The negotiations depict instances where teachers reconciled the critical knowledge and critical components, with the orange arrows showing specific areas that were adapted in this particular workshop in Figure 2.7. Table 2.12 lists examples of negotiation codes.
Table 2.12. Example space of negotiation codes from final inductive coding. These codes represent the arrows between one critical knowledge code and one critical component code.

<table>
<thead>
<tr>
<th>Relevance and Institutional Barriers</th>
<th>“I'm thinking, 'This [workshop] is going be interesting. How are we going to figure out the particulate content in air of chlorhexidine? How on Earth would you do that?' I'm thinking, 'What, we probably don't have that instrument at our school.'”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student Background and SEPs</td>
<td>“Usually, if you're doing a lab and you're not getting the expected answer, or whatever is perceived as the right answer, then students are very anxious about that. And that’s a part of science...I mean, I joke with my students a lot because some of them go in the summer to [the university] and they work in various people’s labs and they come back and they go, ‘I worked the whole summer on this thing, and I never even got any results!’”</td>
</tr>
<tr>
<td>Who is actually doing the science</td>
<td>“So, what we were doing wasn't research, we might be simulating research in some way. And so, if we go back and take this into our classrooms, there's a difference in how we would have to frame it. When researchers speak about it, they can say 'we' and talk about that a lot. [The scientist] is doing that work. So, from our perspective, that narrative would have to be, 'Well, if 'we' as a class, or if 'we' were doing this type of research, what sort of decisions would 'we' make?'”</td>
</tr>
</tbody>
</table>
Three rounds of coding produced 51 codes between critical components, critical knowledge, and space of negotiation. However, during the consensus process, we noticed that certain codes were similar and could be collapsed into a broader category. For instance, Teachers’ perceptions of students’ struggles applying mathematical concepts to chemistry, finding the endpoint using titration, and creating a hypothesis using the open-ended nature of research were initially three separate codes. During this process, we collapsed them into one code (student difficulties) and eventually placed that code into the ‘student-critical knowledge’ category. The research team then organized the codes and categories on a whiteboard and discussed how they related to one another (Figure 2.8). Figure 2.7 depicts the final collapsed codebook and relationships between codes as determined by the authors, eventually leading to Figure 2.4 in the paper when considering the initial framework.
2.9.7 Expansion of Results – Science and Engineering Practices: Asking Questions and Defining Problems

The practice of asking questions and defining problems allows students to explore ideas inspired by the predictions of a model, theory, or findings from an experiment. This practice is open-ended in nature, where students can pursue lines of inquiry that emerge from the experiences with a scientific phenomenon. In this activity, participants form research questions based off local knowledge of road salt deposits and previous data collected by researchers. Johnny captured this perspective in his thoughts about the scientific narrative from the day 1 focus group:

*Those scientific decisions that you make ... why did you take it from this location? Well, we wanna know about location. And then, there was also a narrative component in our conclusion because we said, "Well what's gonna be the effect of this on our cars? What's gonna be the effect of it on the grass?" That's what I think about this being ... how the scientific process leads you to more questions, which is expanding the narrative or...finding out more information, more detail, more connections.*

Outside of the local knowledge mentioned above, Johnny discusses questions that could emerge from relating the content material with personal experiences with objects that students come across in everyday life, such as grass and cars. He also mentions the ‘expanding narrative’ of science, where information gathered from previous questions often leads to more questions. Oftentimes in the classroom setting, this practice can be limited by students’ focus on finding the right answer, as is captured by this dialogue in the day 2 focus group:

David: *What if students then say, "What if I get it wrong?" What are you going to say to them about that?*

Jocelyn: *[jokingly] It's just your grade!*

Johnny: *That's what we do in science, we ask certain things if we think there's going to be a relationship but, we don't know and so we express it the best we can imagine in advance and then see if our idea's right. See what comes up and that's what science is. We don't start out with a right answer, usually we're investigating something we don't know the right answer to. So, there isn't a wrong hypothesis.*

Jocelyn: *Well, can't they adjust it once they start putting everything together on the whiteboard that should be much clearer.*

Johnny: *Yeah, but that's when you're like, "I don't want you to adjust your hypothesis, I want you to reflect on it and say, 'Wow, we didn't even think about the fact that ..."*
whatever’. I mean there’s…confirmation bias, you know? You throw out a hypothesis and you want it to be right in your experiment.

David: Right! For example, one group pointed out different values of chloride ion concentration in different years. Another group suggested investigating the chloride ion concentration based on the depth in the snow from which the sample was taken, and when the sample was taken versus how long after a snow fall.

To shift the class’s focus away from being correct, Johnny discusses the open-ended nature of the scientific enterprise insofar as scientists pursue questions that connect could connect to theory—that a ‘right hypothesis’ does not necessarily exist. Jocelyn and Johnny then discuss how the whiteboard presentations at the end of the activity allow for students to evaluate and adjust their own hypotheses by reflecting on their peers’ data and feedback. David then reflects on an instance where previous data led to hypothesis generation. For this SEP, participants consider how to structure activities resembling scientific practices with how their students behave, embodying both pedagogical and student behavior critical components.

2.9.8 Expansion of Results – Critical Component: Disciplinary Practices

Johnny affirms that learning about tools that accomplish specific tasks makes merging real-world science and his classroom more feasible. David continues the discussion by adding:

*We're talking about tools, and titration is a tool. It makes me come back to this conversation of when we would do this, and we've said a couple of times, "Well, if they already know about titrations," but I look at this in another way as well: as long as you get them to make the decision that, "I need to find some way to figure out that concentration," It's okay to say, "There's a tool for that." Much like you find it in the hardware store, there's a tool we have, and it's called titration, and let me show you how to do it. And so, on that first day, if we do a demonstration on titration, and this lab can still be done.*

Throughout this conversation, the teachers were concerned with how to work with students who might not be comfortable with titration. This ties back to Johnny’s comment in the relevance section where oftentimes titration is taught using fabricated solutions and without much real-world application. Connecting to Johnny’s comments, David continues the analogy by positing that they could introduce titration as one potential tool, amongst many, that scientists use to collect data and show students through a demonstration how it works when students decide it is necessary to perform a titration. David’s idea that someone could replicate a disciplinary
experience in the classroom, where a scientist chooses from a range of tools to complete a given task, also relates to the procedural critical component.

2.10 References


Chapter 3
Scientific Epistemology in the Classroom: How Do Science and Engineering Faculty Represent the Science and Engineering Practices?

3.1 Initial Remarks

This chapter clarifies what we mean by the Western science perspective by exploring the relationship between the Science and Engineering Practices, as a part of the Next Generation Science Standards (NGSS), and perspectives of the scientific knowledge construction process, as demonstrated by science research faculty at a major university. The Science and Engineering Practices are a framework used in science classrooms where students learn science content by mimicking practices used by scientists to construct new knowledge. However, many secondary science teachers’ trainings and backgrounds do not include scientific research, leading to an inauthentic application of the Science and Engineering Practices without examples of how scientists use these practices in the laboratory. The study in this chapter focuses on how scientists and engineers represent the knowledge construction processes of their field through the construction of lessons that were implemented with preservice teachers in an education course that showcased real-word applications of the NGSS in the classroom. The professors in the study provide a nuanced depiction on how they use Science and Engineering Practices within their research through the design and implementation of their modules.

This study utilizes frameworks of scientific epistemology to qualitatively investigate the professors’ perspectives on how knowledge is constructed and validated in their respective disciplines, including personal, practical, and disciplinary perspectives. The disciplinary perspective focuses on the construction of scientific knowledge as a social practice among experts within a specific scientific discipline, the personal perspective focuses on how learners conceptualize scientific knowledge and how that influences their understanding of science, and the practical perspective describes the interplay of the individual and the socially shared practice
of knowledge construction in a scientific discipline. These perspectives were used to qualitatively characterize how the professors in the study represented their research as it relates to the Science and Engineering Practices in the course modules.

Findings from this study include four in-depth cases that portray the epistemological traits informing the professors’ module design and implementation process and how these traits relate to the Science and Engineering Practices. While the traits contained examples of personal, practical, and disciplinary perspectives of epistemology, these perspectives varied drastically depending on the training, experiences, and disciplines of each professor. These produced varied depictions of the Science and Engineering Practices depending on how the professor chose to use the tool. For instance, an environmental chemistry professor used climate change and society to frame how the preservice teachers Asked Questions and Defined Problems, whereas a physiology professor wanted questions to emerge from experiences with finding patterns in mathematical data from a physical model in a laboratory.

The description of these traits can be used to construct a nuanced depiction of the Science and Engineering Practices as it relates to specific disciplines. For instance, in secondary settings, main subject teachers (e.g., biology, physics, chemistry) should use realistic representations of how scientists construct and validate knowledge in scientific fields. While the Science and Engineering Practices offer generalized guidance on how to achieve this aim, clarifying epistemological perspectives could provide richer epistemic experiences for students.

This chapter is being prepared for submission to a science education research journal. Dr. R. Charles Dershimer was responsible for teaching the preservice teacher course. Dr. R. Charles Dershimer and Prof. Ginger Shultz were responsible for supporting the science and engineering professors throughout the design and implementation of their modules and data collection. The author independently completed all remaining work, including data analysis, member checking, and manuscript writing.

3.2 Abstract

The National Research Council advocates for students’ engagement in authentic science practices at the secondary and post-secondary levels. Though the Next Generation Science Standards provide general guidance on how teachers can engage in epistemic practices, many secondary teachers have limited experience with how the practices occur in a scientific setting.
On the other hand, university faculty possess expertise in applying science practices from within their discipline but have little training on incorporating them in their classroom. This article describes an interprofessional learning community where STEM research faculty constructed lessons that represent their current research interests, including applicable Science and Engineering Practices, for a community of practicing teachers. We utilize semi-structured interviews and classroom observation data to construct cases displaying how faculty members represent their discipline. The cases describe how professors’ personal, practical, and disciplinary perspectives of scientific epistemology inform curricular material and interactions with the teachers. Our findings suggest that the Science and Engineering Practices provide a general framework accessible for teachers modeling how scientists construct knowledge. The cases reveal that these practices are highly subject to a scientist’s training and their discipline's unique norms and practices. This analysis can inform more nuanced descriptions of how the Science and Engineering Practices can be applied in classroom settings in ways that more closely resemble how specific scientific disciplines regulate knowledge.

3.3 Introduction

National Education Policy reports call for curricular reform in postsecondary science, technology, engineering, and mathematics (STEM) education, including the incorporation of science practices that resemble active research conducted in laboratories (American Association for the Advancement of Sciences, 2011; President’s Council of Advisors on Science and Technology, 2012). Yet, studies reveal that most teaching in postsecondary classrooms is didactic in nature and does not resemble these practices (Gibbons, Villafañe, Stains, Murphy, & Raker, 2018; Lund & Stains, 2015). While highly skilled in their fields, many postsecondary faculty are not as familiar with reform-based teaching techniques due to lack of training and a view of teaching as competing with other important aspects of their position (Robert & Carlsen, 2017). These factors can be viewed as barriers to implementing science practices in professors’ classroom. However, formal efforts to integrate professors’ research expertise into teaching could be a way to introduce professors to education reforms while developing a clearer understanding of how disciplinary-specific science practices are applied in research contexts (Ford, 2008; Kelly, McDonald, & Wickman, 2012; Robert & Carlsen, 2017). Parallel efforts are occurring in the secondary domain of science education. The Next Generation Science Standards
(NGSS) task teachers to engage students in applying their knowledge to investigate the natural world and solve meaningful problems (National Research Council, 2012; NGSS Lead States, 2013). Russ (2014) acknowledges that “placing scientific practice at the center of science learning honors the expertise of the scientific community that has been developed through a process of continuous refinement and change” (p 389). Scientists themselves view the methods of science (or practices) as an essential epistemological characteristic of science (Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). Recent literature describes how science practice relates to the general populations’ conceptions of the work of scientists (Furtak & Penuel, 2019; Hammer & Manz, 2019; Larkin, 2019; Osborne, 2019; Penuel & Furtak, 2019), the nature of combining science learning and the norms and practices of science disciplines (Russ, 2014; Sandoval, 2005), and contrasting how the work of scientists is taught in the classroom with how students conceptualize the work of scientists (Khishfe & Abd-El-Khalick, 2002; Sandoval, 2005, 2014). The pedagogical focus on scientific practice is further complicated because most teachers are asked to create meaningful representations of science practices for students with little training or experience on how these practices are authentically applied in a scientific context (Anderson, 2007; Capps & Crawford, 2013). It is essential to construct a more nuanced description of how science practices are applied in the classroom in both secondary and post-secondary communities. Facilitating interactions between university science researchers and secondary educators can be a productive way to introduce teachers to authentic science practices (Houseal, Abd-El-Khalick, & Destefano, 2014) while allowing professors the opportunity to represent their research in a classroom setting.

Considering science education reform efforts at the secondary and post-secondary levels, a team of STEM faculty, education specialists, and secondary inservice and preservice teachers created an interprofessional learning community to construct and refine classroom activities that authentically apply tenets of scientific research. The analysis that we present in this manuscript explores how participating STEM faculty represented their scientific discipline while collaborating with science educators. The research questions that guided this study are: (1) How is scientific epistemology represented by university faculty developing and implementing an instructional module around their research? and (2) How do the faculty’s experiences with the module relate to the Science and Engineering practices? These questions could help build a
description of how epistemic practices in the Framework (2012) can be represented in the classroom in discipline-specific ways.

3.3.1 Scientific Epistemology

Epistemology is defined as the study of collective knowledge and the beliefs an individual holds about how knowledge is produced; similarly, scientific epistemology is a “description of the nature of scientific knowledge, including the sources of such knowledge, its truth value, scientifically appropriate warrants, and so forth” (Sandoval, 2005, p. 635). Stakeholders in the scientific enterprise, including scientists, teachers, students, or the general population, hold a scientific epistemology that depends on their exposure to the work of scientists. Extensive research focuses on scientific epistemology (Duschl, 2008) and how people view the nature of science (Lederman, 2013). Because secondary science teachers and research scientists both work to further peoples’ understanding of the work of science, our discussion will be limited to how an individual’s epistemology interacts with the way their scientific discipline constructs and organizes knowledge, primarily from the disciplinary (Duschl, 2008; Ford, 2008; Kelly et al., 2012), personal (Hammer & Elby, 2002; Kelly et al., 2012; Sandoval, 2014), and practical (Sandoval, 2014; Wickman, 2004) perspectives of epistemology.

3.3.2 Disciplinary Perspective of Epistemology

Kelly (2012) posits that individuals navigate two perspectives of epistemology, disciplinary and personal, to learn how science is conducted. The disciplinary perspective of epistemology (herein referred to as disciplinary perspective) is how the scientific field examines issues such as the “nature of evidence, criteria for theory choice in science, the role of theory-dependence in scientific research methodology, and the structure of disciplinary knowledge” (Kelly, 2012, p. 282). The disciplinary perspective focuses on constructing scientific knowledge as a social practice among experts within a specific scientific discipline. Duschl (2008) describes that most scientific work occurs within theory justification or concept modification within the field; that is, scientists concern themselves with building from the work of fellow scientists to ground their research. This description shows that the knowledge construction process is responsive to how scientists respond to new data or new theories that interpret data. For example, research scientists regularly read scientific journal articles and attend conferences to learn
colleagues’ work in their discipline. This information transfers into their laboratory settings, where researchers respond to novel techniques learned from the greater field by applying them in related experiments to build new knowledge. This new knowledge is then reported to and validated by experts and community members through scientific journals and conferences. These disciplinary practices are diverse and field-specific (Sandoval, 2005; Duschl, 2008)—how a chemistry researcher tackles problems deviates from an electrical engineer because a researcher’s tools, methods, and background knowledge varies between disciplinary communities. As a result, people who engage in the sciences are inducted into the norms, practices, and values of specific communities as they move through coursework and interact with other scientists through research activities (Ford, 2008; Ward, 2016).

3.3.3 Personal Perspective of Epistemology

The personal perspective of epistemology (referred to here as personal perspective) focuses on how learners conceptualize knowledge and how that influences their learning. This perspective is concerned with personal views of truth rather than disciplinary considerations of rationality, truth, and justification (Kelly, 2012). In this regard, an individual constructs their views of the scientific process through formal and informal experiences. Bell and Linn (2002) report that beliefs about science are shaped by available information resources, such as news accounts, consumer reports, historical summaries, journal articles, textbooks, and materials published on the internet. Each source provides an account of authority and knowledge construction and offers varying degrees of bias that affect the presentation of results. For instance, popular news often ignores or implies the limitations of the methodologies of the field to build a controversial account that justifies a scientific endeavor. Individuals who build their understanding of science using these sources “as an insight into the inquiry process may not understand that these successes stand in contrast to failures, faulty methodologies, and misguided decisions typical of complex investigation” (Bell & Linn, 2002, pp. 324-325). The personal perspective also includes an individual’s conception of their academic domain and important practices considered to evaluate knowledge (Sandoval, 2014). Individuals situate their personal perspective within the disciplinary perspective of their specific scientific domain (Hammer & Elby, 2002; Hofer, 2001). We would expect a chemistry professor to have differing epistemological beliefs when comparing their field with another scientific discipline (e.g.,
electrical engineering) due to varying levels of experience with other disciplines’ perspectives. Also, epistemological beliefs between two chemistry professors inherently differ due to the complex and situated nature of the prior experiences that led to their specific beliefs. Therefore, the personal perspective of scientific epistemology is highly individualized based on context, resources, and experience.

3.3.4 Practical Perspective of Epistemology

Wickman (2004) and Sandoval (2014) recognize the joint activity of personal and disciplinary perspectives through a practical perspective of epistemology (herein referred to as practical perspective) of individuals participating in the socially shared practice of knowledge construction in a scientific discipline to solve particular problems situated in particular locations at particular times. From the practical perspective, an individual is a participant within a larger social paradigm, where both the individual and discipline are responsible for the construction, evaluation, and organization of knowledge. For instance, an expert research scientist uses their personal perspective as they participate within their greater scientific discipline, utilizing the disciplinary perspective’s collective norms and practices to inform experiments and collect data that eventually contributes to and shifts the knowledgebase of the discipline. Furthermore, within classroom experiences, the disciplinary perspective influences how instructors use their personal perspective to conceptualize and present scientific content to better represent work of scientists (Sandoval, 2014; NGSS Lead States, 2013) and how students interact with scientific information (Wickman, 2004). Therefore, it is essential to consider how research faculty are inducted as participating members of their discipline to understand better how practical epistemologies interact with personal and disciplinary perspectives. Figure 3.1 summarizes the relations between the three perspectives. In addition to perspectives of epistemology, we will outline how disciplinary learning occurs for an individual (Ford, 2008; Ford & Forman, 2006) and discuss structures that promote disciplinary learning in secondary and postsecondary education.

3.3.5 Disciplinary Learning

An expert’s role in science may include helping novices learn the norms and practices
associated with a disciplinary perspective, including how knowledge is organized and structured. This process is similar to how novices engage in legitimate peripheral participation while being apprenticed in situated learning theories (Lave & Wenger, 1991). In addition, community-supported learning in science often includes professors, postdoctoral students, or advanced graduate students mentoring early graduate and undergraduate students as they become acclimated to the research laboratory culture (Ward, 2016). Ford (2008) describes that this transition involves individual students working on research teams where people collaborate to define research questions, collect and process data, write research papers, produce posters for professional meetings, and design inventions, all of which serve to progress the field by providing a structure to critique expanding knowledge.

If novices are to grasp how the scientific disciplines work, they need to engage in practices used by scientists to decide what counts as knowledge in their field. Such aspects of practice are conceptualized by Ford and Forman (2006) as disciplinary learning and include (1) a social aspect of scientific practice where communities of investigators participate in public debates about explanatory accounts of nature; (2) a material aspect of scientific practice where scientists engage with “framing, measuring, and representing nature’s behavior to support arguments in the public realm” (p. 4); and (3) practice as an interplay of roles where the scientist functions as someone who constructs and critiques knowledge claims. These disciplinary

---

**Figure 3.1.** Summaries of Personal, Disciplinary, and Practical epistemology and how they relate within the science epistemology framework.
learning practices determine authority for deciding what counts as knowledge in scientific disciplines and are what students (novices) should learn in classrooms if they are to gain a fundamental understanding of and participate authentically in scientific work (Ford, 2008). Through novice-expert interactions, learners encounter and explore ideas in a subject, the uses for these ideas, and ways these ideas are validated; that is, students learn what constitutes legitimate knowledge in a field. As students engage in conversations with others, they draw on their expertise to explain, extend, and reflect on their ideas to gain exposure to the habits of mind exhibited by disciplinary experts (Walker & Sampson, 2013).

These disciplinary learning practices shift a novice’s personal perspective to become more aligned with the values portrayed by a field’s disciplinary perspective, changing the nature in which a novice scientist engages with the field. For instance, as younger science graduate students become acclimated to their laboratory cultures, they develop experiments related to research that older members of their community have successfully defended in the public sphere. They present their findings at conferences and write papers to engage in debates about their explanatory account of nature and eventually construct and critique knowledge claims as they present their findings to their doctoral committee (e.g., prelim, candidacy)—they participate in all three aspects of disciplinary learning as novices to learn how their field constructs and validates knowledge. As they develop expertise, their personal perspective shifts to incorporate more sophisticated viewpoints on how their discipline operates (Chi, Glaser, & Farr, 1988; Hofer, 2001; Samarapungavan, Westby, & Bodner, 2006). Once the student demonstrates that they can perform at an acceptable level, they gain greater autonomy working on projects that align with their own research goals and produce new knowledge (Ward, 2016)—the nature of their practical epistemology shifts. Disciplinary perspectives vary between subjects (e.g., chemistry, electrical engineering) and could be explored by observing how faculty exhibit epistemological traits when they portray their research to people outside their discipline.

3.3.6 Structures that Promote Disciplinary Learning

The Framework for K-12 Science Education (2012) laid the foundation for disciplinary core content within Science and Engineering Practices. The eight practices improved upon previous reform efforts by clarifying that the scientific process involved a set of regularly used practices by scientists to introduce and validate knowledge claims. For instance, the Framework
(2012) discusses that *Engaging in Argumentation from Evidence* is an “essential element both for building new knowledge in general and for the learning of science in particular…as all ideas in science are evaluated against alternative explanations and compared with evidence” (National Research Council, 2012, p. 44). Compared with Ford & Forman’s (2006) disciplinary learning practices, the NGSS Science and Engineering practice of argumentation engages students in the social learning practices of scientists where students mimic the knowledge-production process of scientists by simultaneously conveying their ideas in a public sphere while critiquing each others’ claims to understand the nature of scientific claims. This argumentation process, generally performed within classroom environments, contributes to students’ *personal* perspectives. Students are rarely allowed to explore both the *practical* and *disciplinary* perspectives within the Science and Engineering Practices unless the scientific activity uses information produced by students to contribute to a greater body of scientific knowledge (Houseal et al., 2014). The *practical* and *disciplinary* perspectives require active participation from within a community that utilizes specialized knowledge—students and teachers need access to these disciplinary communities to learn how the Science and Engineering Practices are applied in discipline-specific ways to construct new knowledge. Exploring these discipline-specific epistemological traits could offer insight into how the Science and Engineering Practices relate to the greater scientific enterprise.

### 3.4 Methods

This study used qualitative methods to document the characteristics of faculty scientific epistemology that drive representation of their research into teaching. We focus on faculty for two reasons: (1) because they are experts in their respective field and have a refined understanding their field’s disciplinary perspective from experiences engaging their personal and practical perspectives and (2) because they regularly communicate their scientific epistemology to diverse audiences as a part of their professional role. We conducted the study in the context of a full-semester secondary science preservice teacher education course where four science professors were recruited to construct one lesson per week over three consecutive weeks (referred to herein as a module). Modules focused on an aspect of each faculty member’s research. They were meant to engage inservice and preservice science teachers with ideas and practices related to current research that teachers might use in a secondary science classroom.
Each lesson within the module was three-hours in duration. Module design served as a phenomenon upon which the faculty reflected, affecting the trajectory of the following lessons and revealing pedagogical considerations that informed their teaching practice.

3.4.1 Population and Participants

Participants included two education specialists, four university faculty, twenty preservice teachers (middle and high school), and a range of practicing high school teachers. Education specialists, herein referred to as specialists, were situated in a school of education and a science department and had experience helping preservice teachers and college faculty develop pedagogical practices. We recruited science faculty (scientists), herein referred to as faculty, from a large research-intensive institution in the Midwest based on communicated interest in integrating authentic research practices into their teaching. The faculty were assistant and full

Table 3.1. Summary of faculty participant background information pertinent to the study.

<table>
<thead>
<tr>
<th>Title</th>
<th>Michael</th>
<th>Lindsay</th>
<th>Byron</th>
<th>Eve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching Experience</td>
<td>Full Professor</td>
<td>Assistant Professor</td>
<td>Full Professor</td>
<td>Assistant Professor</td>
</tr>
<tr>
<td>Previous Experience with</td>
<td>10 years in a highly</td>
<td>&lt;5 years in a department</td>
<td>&lt;20 years in a department</td>
<td>&lt;5 years in a department</td>
</tr>
<tr>
<td>Incorporating Disciplinary</td>
<td>structured environment</td>
<td>that is open to educational</td>
<td>that is open to educational</td>
<td>that is open to educational</td>
</tr>
<tr>
<td>Knowledge in Instruction</td>
<td></td>
<td>shift</td>
<td>shift</td>
<td>shift</td>
</tr>
<tr>
<td>Module</td>
<td>Model Lung</td>
<td>Environmental Research</td>
<td>Scaling, Modeling, and</td>
<td>Qualitative Engineering</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Anatomy</td>
<td></td>
</tr>
<tr>
<td>Use of Specialists</td>
<td>Met weekly throughout</td>
<td>Met 3-4 times throughout</td>
<td>Seldom</td>
<td>Met 3-4 times throughout</td>
</tr>
<tr>
<td></td>
<td>the semester</td>
<td>the semester</td>
<td></td>
<td>the semester</td>
</tr>
<tr>
<td>Nature of Specialist</td>
<td>Constructing the model</td>
<td>How to shift lessons</td>
<td>Describing structure of</td>
<td></td>
</tr>
<tr>
<td>Interactions</td>
<td>lung. Co-teaching to</td>
<td>originally intended for</td>
<td>the preservice teaching</td>
<td></td>
</tr>
<tr>
<td></td>
<td>build structure in the</td>
<td>undergraduates to better</td>
<td>course</td>
<td></td>
</tr>
<tr>
<td></td>
<td>class to support</td>
<td>accommodate high school</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>class to support</td>
<td>students</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>discourse</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
professors and had a range of experience in teaching and developing curricula demonstrating Science and Engineering Practices through authentic research. Summaries of the characteristics of faculty participants can be found in Table 3.1. Specialists served as consultants to faculty as needed to inform module development. The course instructor, who was also a specialist, advertised the course as an opportunity to explore applications of the Science and Engineering Practices from the NGSS (National Research Council, 2012; NGSS Lead States, 2013) in secondary science classrooms through authentic research practices. Practicing high school teachers, who were mentors of the preservice teachers, were invited to participate in the course. During any given week, between two and eight practicing high school teachers were present. We use the word teacher to describe the preservice teachers and mentor teachers who participated in this course. All participants self-selected into the research that was conducted and given pseudonyms to preserve confidentiality.

3.4.2 Data Collection

Our data collection strategy began with capturing the module's implementation, focusing particularly on faculty presenting scientific disciplinary content and interaction with the teachers. In addition, the implementation included a structured verbal reflection process that faculty members engaged in during their modules in the preservice teacher course. By doing this, we aimed to capture epistemological details in the structure of the module itself and from faculty members’ reflections, both during and after the modules, to learn more about “epistemic commitments that are not necessarily visible in the interaction…the goals that motivate forms of participation, and how individuals appropriate community practices” (Sandoval, 2014, p. 386).

To capture the faculty members’ planning and implementation processes, we collected video observations of each lesson in the preservice teacher course throughout the semester (9 hours per faculty participant, 36 hours total). The observations consisted of the lesson implementation and an embedded reflective conversation that included teachers reflecting with the faculty member on how they experienced the module and their considerations before implementing the material in their classroom contexts. Members of the research team collected field notes documenting pedagogical moves, non-verbal interactions, and insights to note pedagogically and epistemologically important incidences in the video, which were flagged for analysis. To capture the role of the specialists’ interaction with faculty before the lesson, we
constructed a specialist reflection protocol that included general questions about planning that applied to all faculty participants, such as: “How many times did you meet with this person before the lesson? What did you talk about?” and “Between the lessons, was there any informal reflection process that you initiated to make the lessons flow better or relate more for the students?” Specialists were also asked participant-specific clarifying questions on the planning process based on patterns noticed between the final interview and observations.

The specialists conducted reflective semi-structured interviews, located in the supplemental information after faculty members taught their modules to learn more about how the faculty members experienced the planning and teaching process with the teachers. The interviews were 90 minutes in length and conducted in an informal setting (e.g., cafes and restaurants), including questions about the planning process, such as: “When you were working with the specialists and co-planning what you would be doing, what was that process like?” and “What would you identify as major challenges to the process of designing a lesson?” Reflective questions were asked about faculty interactions with teachers in the modules, such as: “What did you learn from working with participating educators?” We asked probing questions, when appropriate, to clarify comments alluding to teaching in a non-traditional format, working with the teachers, or implication on their practice.

3.4.3 Analysis of Data

All audio from the interviews and videos were transcribed and coded using NVivo version 12 (QSR International, 2018). Final interviews with participating faculty were reviewed and analyzed using a grounded theory approach (Glaser & Strauss, 1967; Lincoln & Guba, 1985) characteristic of naturalistic inquiry. We coded passages of interest concerning our research questions to address the use of Science and Engineering Practices in each module, pedagogical practices present in each module, statements conveying conceptions of scientific epistemology, and comments related to the value of working with practicing educators. We applied the codes to all faculty interviews and used a constant comparison method during the coding process to determine commonalities between sources (Nowell, Norris, White, & Moules, 2017; Strauss & Corbin, 1990). We placed codes and potential themes in a codebook, which were analyzed and defined by the research team to generate consensus, specifically on codes that may not have appeared in all cases (Saldaña, 2016). Once we defined the codes from the faculty interviews,
they were applied to field notes and videos to determine if the patterns remained consistent across sources. Interviews with specialists were analyzed using the same codes to detail the nature of their support while working with faculty, looking specifically for similarities in the specialist account to what faculty mentioned in the faculty interviews.

We constructed descriptive cases to detail faculty teaching experience and philosophy, departmental context and structure, module design and specialist contribution, and notable interactions between the faculty participants and the teachers. We then subjected the cases to a member check to validate how the data analysis represented their experience (Hays & Singh, 2012). During member checking, faculty read their cases and were asked to focus specifically on threats to anonymity, tensions between researchers and faculty perceptions of their experience, and additional insights based on the faculty members’ discipline. Each case went through multiple iterations of member checking while being condensed to an efficient format for the reader. Summaries of each module are found in Table 3.2, and the full cases are found in the supplemental information.

3.5 Findings

The following results address our research questions: (1) How is scientific epistemology represented by university faculty developing and implementing an instructional module around their research? and (2) How do the faculty’s experiences with the module relate to the Science and Engineering practices? We seek to construct a nuanced depiction of how scientists, as disciplinary experts, represent the Science and Engineering Practices. This section is organized into four cases corresponding to a different scientist who participated in the study. Each case contains two parts: a description of epistemological traits that emerged in the module design and implementation process and a discussion on how the emergent epistemological traits relate to the Science and Engineering Practices. Table 3.3 summarizes the relationship between the components of the modules and the Science and Engineering Practices.

3.5.1 Michael — Mangling of Practices

Michael paints a clear picture of his discipline’s norms and practices by describing how he teaches classes in his department. To Michael, the research process begins with exploring the explanatory power of a mathematical model. He describes his teaching process to the teachers in
the course as a problem of optimization, where the teachers give students the tools and data necessary to build a model and the students must work through the variables and programming in a trial-and-error-like fashion. Reflecting on his usual approach to teaching, he mentions:

(The students) have some computer codes, and they have the (materials), and they know how to access it, get it from (the course management system), and download and run it. Then we have some really simple questions: “What if you change this variable? If you modify this thing in this way, what happens?” “Explore the model...play around with this device and see how it works.”, “How does air come in? What happens to the pressure when air goes out?” ...that kind of thing. [Michael, Observation 3]

This teaching style describes how scientists tackle problems within Michael’s discipline, where researchers use mathematical models to describe complex biological systems. Often, scientists in his research group will find models from previous research and explore the data set, finding and testing variables to develop research questions that determine whether a model accurately applies to a wide range of conditions.

From Michael’s disciplinary perspective, the research process may not have a clearly defined focus until the researcher understands the model by analyzing iterations of data and changing specific variables. Continuing with describing his teaching process in his department to the teachers, Michael mentions:

We might have some open-ended (problems) and say, “Here’s a data set, we want you to analyze this data set with this model. What do you have to do...to modify the model to capture some different phenomena.” There’s a couple of us walking around the room, looking over people’s shoulders, saying, “What have you done?” trying to guide them through it. It’s open-ended. Sometimes people fail, and then we have to say, “Everybody stop. Let’s talk on the board about what we’re doing.” [Michael, Observation 3]

Michael introduces a problem to his class only after the students have experience with the model, asking the students to modify the model and determine its effect on the system’s output. The problem is open-ended to create a mathematical model that better describes the phenomenon, and the students independently choose variables to explore from within the system to determine how it affects the output.

From a personal perspective, Michael describes that being bold in challenging preconceptions and making mistakes is a characteristic that helped him become successful in his field. He discusses that students are hesitant when they are unfamiliar with the materials and procedures. Regarding working with computer modeling systems in his departmental course,
Table 3.2. Summaries presenting important characteristics of each faculty member’s modules. Detailed overviews are provided in the supporting information.

<table>
<thead>
<tr>
<th>Michael</th>
<th>Lindsay</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experience and philosophy</strong></td>
<td><strong>Experience and philosophy</strong></td>
</tr>
<tr>
<td>• Michael’s field is highly interdisciplinary, drawing from physiology, computer science, mathematics, and biology to understand the variables of a system and how they relate to and affect the system</td>
<td>• Lindsay’s research takes traditional instruments that are developed in a controlled laboratory setting and brings them to extreme environments to capture data that is highly contextual</td>
</tr>
<tr>
<td>• Michael designed an experience where teachers developed a mathematical program based on data collected from a physical model of a physiological system</td>
<td>• Lindsay wanted her module to have a clear connection to the broader impacts of her research and sought to infuse discussions on current news, science articles, and how scientific claims adapt depending on the audience</td>
</tr>
<tr>
<td><strong>Departmental context and structure</strong></td>
<td><strong>Departmental context and structure</strong></td>
</tr>
<tr>
<td>• Michael is a young and experienced full professor in a highly successful, research-oriented department associated with the medical school</td>
<td>• Her department is open to unique applications of laboratory research and allows faculty to develop courses that align with the content in traditional classes while introducing students to specific, research-oriented applications of the material</td>
</tr>
<tr>
<td>• Teaches upper-level undergraduate classes for majors in his field focusing on replicating and modifying computational biological models portrayed in seminal literature</td>
<td>• Teaches introductory undergraduate laboratory and graduate lecture courses</td>
</tr>
<tr>
<td><strong>Module design and specialist contribution</strong></td>
<td><strong>Module design and specialist contribution</strong></td>
</tr>
<tr>
<td>• Michael and the specialist met twice monthly for six months to design the module, construct the model lung, and create teacher supports throughout the module</td>
<td>• Lindsay and the teaching specialist collaborated to shift undergraduate course material to be better suited for secondary setting</td>
</tr>
<tr>
<td>• The teachers interacted with a model lung with easily accessible, interchangeable materials to explore the effect of different variables on input/output pressure by attaching a pressure sensor to the model</td>
<td>• To develop the module, she collaborated with education-oriented graduate students in her lab to design an experience where teachers engage in the process of thinking like a scientist through selecting areas in their contexts to collect environmental samples and analyze them using titration</td>
</tr>
<tr>
<td>• Due to lack of experience with teaching in this setting, Michael relied on the specialist to establish classroom structures for the teachers during the activity (e.g., think pair share, discourse strategies) and teach the lesson</td>
<td>• Lindsay promoted discussion on current news, science articles, and source validity to field a greater discussion on discussing potentially sensitive topics that could have political implications, such as climate change, to high school students</td>
</tr>
<tr>
<td><strong>Notable interactions with teachers</strong></td>
<td><strong>Notable interactions with teachers</strong></td>
</tr>
<tr>
<td>• Teachers initially played with their models, learning how different components of the lung system interacted with the pressure output</td>
<td>• Lindsay led collaborative discussions on finding patterns in the data sets and connecting the patterns to the geographical location in which the teachers collected samples</td>
</tr>
<tr>
<td>• Michael functioned as a disciplinary expert, offering insight to teachers on variables to shift and connections to relating research</td>
<td>• Teachers engaged in discussions with Lindsay about how to structure discussions about science and society</td>
</tr>
<tr>
<td>• Michael stepped in as a primary instructor to guide teachers through the computation process using excel</td>
<td>• In response, Lindsay adapted her module to provide resources and personal stories for teachers to help them engage students in productive discussions on science and society</td>
</tr>
<tr>
<td>• Michael circulated around the room, answering questions, helping teachers troubleshoot their models, and challenging them to consider different medical conditions that would shift their model</td>
<td>• Lindsay addressed teacher insecurities about not completely understanding the material they were learning by reflecting on how graduate students learn how to be scientists</td>
</tr>
<tr>
<td>• Module ended with many of the teachers still trying to understand the data they were collecting with the model</td>
<td></td>
</tr>
</tbody>
</table>
**Byron**

**Experience and philosophy**
- Byron’s field is highly technical and theoretical, using complex statistics to analyze large amounts of quantitative data regarding celestial systems.
- Byron considered that secondary education commonly embodies the mindset that traditional disciplines are distinct, resulting in student and teacher engagement with discipline-specific content using discipline-specific problem-solving strategies and rarely learning with a cross-disciplinary perspective.

**Departmental context and structure**
- Byron teaches technical higher-level courses along with more traditional introductory courses in his department.
- He serves on committees to restructure introductory courses in his department to make his highly technical discipline more accessible to a broader range of students who are non-majors.
- Serves in leadership roles at the college-level to support faculty in developing and implementing active and relevant teaching strategies.

**Module design and specialist contribution**
- Byron modified a previous lesson where students think about how scaling applies to biological concepts such as evolution and anatomy.
- Byron and the teaching specialist met once due to his previous experience in developing interdisciplinary course material, discussing the overall structure of the modules.

**Notable interactions with teachers**
- Using the information gathered from a community-building activity, Byron constructed the activities of his module to better relate to teachers’ backgrounds, teaching contexts, and students.
- Byron focused on modeling the interdisciplinary nature of science through having teachers measure the length of femur bones from organisms on an evolutionary scale, comparing their masses and determining scaling laws.
- Teachers focused on relating the results of the module to greater issues in society.
- Byron built time into the module for teachers to reflect how they can best adapt the material to relate to students in high school settings; he also asked questions that promoted discussion to inform his own teaching practice.
- Teachers and Byron discussed ways to support students in analyzing and visualizing data.

**Eve**

**Experience and philosophy**
- Eve studies engineering design processes and strategies that support successful design outcomes.
- Eve wanted to design an experience that gave the teachers an overview of the engineering design process that captures both the technical and social components of engineering.

**Departmental context and structure**
- Eve teaches engineering design courses that incorporate human-oriented design approaches, pushing engineering students to think more broadly than the functional aspects of the artifacts they are designing.
- Her department is diverse in faculty research areas, which provides her opportunities to incorporate interdisciplinary perspectives in her studies.

**Module design and specialist contribution**
- She combined a solar oven design lab with a lesson she teaches where students develop qualitative interviews to inform variables that should be considered for the design.
- Eve and the specialist met twice to discuss the structure of the module and how to frame the material to people who are not as familiar with engineering.

**Notable interactions with teachers**
- Eve taught the teachers using structures that resembled her university classroom, where common engineering vocabulary was introduced along with examples, cases, and activities that helped teachers conceptualize the information.
- Teachers constructed qualitative interviews, conducted the interviews with people Eve invited to the workshop, and collaboratively analyzed data to inform their design.
- Eve modeled for teachers the process of using qualitative data sources to inform technical specifications while leading discussions on tradeoffs when making shifts in design.
- Throughout the module, Eve and the teachers discussed common technical conceptions of the role of engineers and ways to incorporate non-technical aspects into the engineering process to include more students.
- Eve provided resources to teachers on how they can use lessons they already teach to incorporate engineering design processes.
| Table 3.3. Summaries of how the faculty members’ modules relate to the Science and Engineering Practices. |
|------------------------------------------|-----------------|-----------------|-----------------|
| **Asking Questions and Defining Problems** | Michael: Using a model lung to find mathematical relationships to describe health conditions | Lindsay: Determining a relationship between geographical location and ion content in environmental samples | Byron: Determining a scaling relationship using variables (e.g., femur length, volume, body mass) to explore evolutionary shifts in biology | Eve: How to incorporate contextual and cultural factors into the design of a solar oven through human-centered design |
| **Developing and Using Models** | Teachers used a physical model of a lung to create a mathematical model | Not present | Teachers plotted data and found a mathematical model using line fitting | Teachers thought about hypothetical design factors for a solar oven prototype |
| **Planning and Carrying out Investigations** | Teachers manipulated the model lung and tested how certain variables affected the input/output pressure | Teachers chose locations around the community to collect samples based on the research questions they developed; samples were analyzed using titration | Teachers developed an experimental protocol to measure and variables (e.g., femur length, volume, body mass) | Teachers developed an interview protocol to learn more about stakeholder needs; Eve invited campers into the classroom for teachers to interview |
| **Analyzing and Interpreting Data** | Pressure sensors attached to model lung resulted in data in an excel spreadsheet | Teachers loaded ion concentration into a crowdsourced spreadsheet; concentrations were then presented using plots | Teachers plotted variable data using graph paper by hand and discussed line fitting and error | Teachers found patterns in stakeholder interview data to determine variables to shift in the solar oven design process |
| **Using Mathematics and Computational Thinking** | Teachers analyzed data in the excel spreadsheet to find patterns and mathematical relationships | Math was used to calculate concentrations to analyze data | Teachers made a log-log graph and a line of best fit while discussing procedures for handling error | Eve led discussions conveying the need for both technical and qualitative aspects to be represented in engineering |
| **Constructing Explanations and Designing Solutions** | Teachers manipulated lungs to simulate health conditions and used mathematical models to describe output | Teachers explained the relationship between ion concentration and geographical location | Teachers discussed scaling laws based on their data and plots; teachers and Byron discussed interdisciplinary nature of solving complex problems | Teachers proposed shifts to a solar oven prototype and weighed the pros and cons of making adaptations to the initial model |
| **Engaging in Argument from Evidence** | Not present | Not present | Not present | Not present |
| **Obtaining, Evaluating, and Communicating Information** | Teachers worked across groups to describe their process and results to inform other groups’ experiments | Teachers and Lindsay discussed how to convey implications of results to a broader community and represent science that may not be their expertise | Teachers and Byron discussed the greater role of science, how it is represented as disciplinary, and how multiple disciplines can work together to solve societal problems | Teachers built consensus between groups around design specifications based on user data; Eve and Teachers discussed ways to represent distinct engineering norms in classrooms |
(The) last lab (I taught) …I was building a very simple model, a simulation, and there’s this very strange barrier to wanting to play around…I think writing formalized steps gets people engaged. I was like, “You can’t break the computer. You can’t break a virtual lab. Let’s just try whatever you want.” And they’re like, “Okay. Like, are you kidding me?” We had a parameter, and I said, “What if we changed that parameter to square root of negative one.” …This weird thing mathematically, right? Everyone was like, “No, no, no, no! I don’t want to talk about that. That’s getting way too complex” (I said) “Let’s just see what happens. Let’s type it and press run.” [Michael, Final Interview]

In this quote, Michael discussed how he could model the optimization process—that sometimes students need to try the process and experience difficulty to become more attuned to how virtual labs work. This process is like how researchers in his field adapt a single, well-established model to describe a wide range of physiological systems undergoing a shift due to health conditions.

Michael’s case provides insight into the difficulty of portraying disciplinary practices to teachers with little background experience in the field. Michael constructed an activity that aligned closely with the work done in his laboratory. Throughout the module, Michael spent substantial instructional time clarifying background material and suggesting how teachers could move their experiments forward. However, many teachers struggled with connecting their data to the bigger picture. As a result, the module ended without meeting the objective of establishing a mathematical model and applying it to other system variables. In his final interview, he mentioned, “I wanted to close the loop and have them…do something with changing, adding, or subtracting something from the model or analyzing the data themselves. We just didn’t have the time to do all that” [Michael, Final Interview].

**Connections to the Science and Engineering Practices**

Michael’s module focused heavily on how scientists apply the Science and Engineering Practice of Developing and Using Models in their laboratory context. The Framework (2012) states that conceptual models are “a tool for thinking with, making predictions, and making sense of experiences” (p. 56) and that scientists use them to “represent their current understanding of a system under study, to aid in the development of questions and explanations, and to communicate ideas to others” (p. 57). In this instance, Michael wanted the teachers to develop a mathematical model from pressure data created by a physical model of a lung. He hoped that data from the models would inspire the teachers to develop questions that extended the model to
other health scenarios. He also mentioned that models in his field are used to represent the current understanding of a system when he described how he has his students explore previously developed models in his classroom. The Framework (2012) also mentions that “it is important to recognize the limitations (of models) ...because all models contain approximations and assumptions that limit the range of validity and the precision of their predictive power” (p. 56). While not stated explicitly, both Michael’s module and his description of classroom activities embody the perspective that new knowledge in his field depends on exploring the model’s limits to improve the model itself. To do this, scientists compare their predictions with reality and adjust the model, which is why trial-and-error seems to be a valuable epistemic practice for Michael’s students to learn if they are to engage further with his field.

In his module, Michael’s disciplinary perspective demonstrated the interconnected nature of the Science and Engineering Practices. For instance, to Construct an Explanation of alternative applications of a well-known model, researchers Ask Questions while developing an understanding of the current theory behind the model. Researchers then Plan and Carry Out Investigations using modifications to the model and Analyze and Interpret Data that result as an output through Using Mathematics and Computational Thinking. From the disciplinary perspective, these practices are all a component of Developing and Using Models that scientists in Michael’s field use to ground their research. Each practice is inseparable from one-another, happening instantaneously as the scientist ‘tries out’ different modifications to the model and compares the results to the data from the actual biological system. Michael’s scientific narrative resembles a Mangle of Practice (Pickering, 2010), where the scientist uses socially-determined scientific tools (e.g., computer modeling, line fitting, pressure sensors) to construct an understanding of the material world (e.g., the human lung). In this vision, a scientist’s conception of both social and material entities shift as their understanding of the phenomenon grows, creating a construct where any number of science practices are conjunctively applied as needed by the scientist to construct a more sophisticated explanation of the material world. As Michael found out in his module, such a representation is difficult to portray to people outside of his field due to the unstructured and complex nature of experimentation.
3.5.2 Lindsay — Communication, Context, and Disciplinary Authority

Lindsay’s research involves transporting traditional instruments developed in controlled laboratory settings to extreme environments to collect unique data specific to a geographical location. The contextualized nature of her data leads her to fuse the results of her experiments with the culture and broader impacts in her reports, often informing political causes related to her work. Lindsay’s module embodied this disciplinary perspective by asking the teachers to collect and analyze samples from around their community, demonstrating that science that is taught in the classroom often relates to the local communities of their students. Much of the discussion in the module focused on how to select activities that relate to the broader community, of which Lindsay mentions:

So, if I were you and I were thinking about how could I teach this in the classroom, one of the things that I would want to do is engage in the local area. Think about what’s around you! Since we’re near the Great Lakes: How do we think about the Great Lakes? Well, you can think about algal blooms and about how algal blooms are increasing in the Great Lakes. That impacts the Toledo water supply. You can talk about biology, the algae, there’s many different opportunities! [Lindsay, Observation 3]

From these experiences, Lindsay operates with the practical perspective that science should expand beyond the confines of the laboratory to relate to the contexts of the students.

Teaching, to Lindsay, is synonymous with advocacy. On a pragmatic level, she views her classes as a space where students can learn the broader applications of the content. Because of this, Lindsay incorporates news articles, videos, and scientific papers in her classes and asks students to reflect on how these sources relate to important topics in their lives. For example, in introducing a topic like climate change, Lindsay mentions:

I often get asked whenever I’m talking about something like this: “Okay, now you’ve told me these things that are happening and disease will spread and storms will increase, so what are we going to do? This is really depressing, and I feel like there’s nothing we can do about it.” I found this nice video that’s about climate change solutions—things that individual people can do, research that’s happening... I think it’s six minutes of your time and I would encourage you after class to look at that. [Lindsay, Observation 1]

As a result, even though the module focused on collecting and analyzing data from the teachers’ local community, whose discussion centered on the larger implications of Lindsay’s work and how the teachers can guide their students through the intersection of science, politics, and
society. Reflecting in her final interview:

*I think there’s a big responsibility as a scientist to communicate. If you don’t write a paper about your stuff, it doesn’t exist. I think there is an ethical responsibility to help with the fact that...twenty percent of the US adult population is science illiterate...To me, this is a responsibility in a place where we can give back.* [Lindsay, Final Interview]

As a result of her personal perspective, she provided opportunities to discuss how scientific data gets interpreted in different contexts so that her students can assess the validity of claims in a wide variety of sources.

In the classroom, the teachers found Lindsay’s discussion of the societal implications of science intriguing since many of them were inexperienced with the scientific knowledge-construction process. Speaking as an authority about complex topics, such as climate change, and leading discussions were particularly concerning to the teachers. A part of this conversation is detailed below:

Teacher 1: *As far as informing yourself—you have to know what you don’t know. So, for this whole (environmental) issue that we’re talking about, do I know what’s going on or not? Because that’s when you know you have to look up something. So, I guess an issue that I have is what do I need to know? Or...How do you know that you don’t know something until it comes to you?*

Teacher 2: *I try to think about what ways might I create access points for my students to understand things. Because a lot of students distrust science—It’s this big authority that you can’t do away with and they can’t really experience it or gain trust—I’m looking at this and I’m wondering what tools do they (the scientists) use, and how do those tools work? I just have to tell the kids, and they have to trust me. For me to speak about...authority, I gotta understand how those tools work as well. So, there’s a lot of deep stuff here that we should cover in science class. But if we can’t get to it, I don’t understand the tools that are used, how the data is collected, how it’s analyzed, and what models you make. It’s tough...and at the end of the day I want them (the students) to make their own decisions.*

Lindsay: *So, you feel like you can’t talk about science because you don’t know, and I would say that, at least from what I’ve seen working with undergraduates and graduate students, most people don’t get to the point of understanding what they don’t know in an area until about the third year of grad school...I bring that up from the standpoint that you have to make decisions about what is enough in order to teach that area and to bring something meaningful to the students because, otherwise if I wanted to be cynical, I’d say...that means none of us are qualified to teach high school. You know? We haven’t gotten a Ph.D. in every single topic that’s taught!* [Lindsay, Observation 3]
In this instance, the teachers discussed their insecurity about working with and conveying disciplinary knowledge to students due to their lack of expertise in the subject. Lindsay engaged with the insecurities of the teachers by affirming that it is challenging to convey content authoritatively when you are moderately knowledgeable about the material. She continued describing tenets of her practical perspective with a story about when she was a panelist as an “expert.” Still, she felt like she could not contribute because the topic was on a different subdiscipline within her field (quote omitted to maintain confidentiality). Connecting scientific authority to the example she gave about the Great Lakes algal blooms, Lindsay mentions:

> But, to me, if you were going to have to teach it, I would think about what...you feel comfortable with, what you are interested in, and what’s nearby that the students can connect to...and take it piecewise to figure out “what do I know about that one topic?”, rather than worrying about everything. Because doing that, at least for me, would be very, very scary. [Lindsay, Observation 3]

Her potential solution captured an important point when considering developing lessons that contain research questions—that teachers should identify salient problems related to their context and focus on a topic that interests both the teachers and their students.

*Connections to the Science and Engineering Practices*

Teachers collecting and analyzing snow samples in their community embodies the Science and Engineering Practice of *Planning and Carrying Out Investigations*. The Framework (2012) discusses that students need to experience “investigations to test explanatory models of the world and whether the inferences suggested by these models are supported by data” (p. 59). Lindsay’s module demonstrated an important distinction in her research, where analytical instruments are the *tools* used to analyze data from samples collected from the local area. Instead, the module offered agency in terms of *where* the teachers could collect samples from around the community, and the titration served as a disciplinary tool used to generate empirical data to test their ideas about the chemical composition of the snow that they collected. Lindsay made a point to include tenets of *Obtaining, Evaluating and Communicating Information* because of her personal views on the importance of scientific literacy. A significant part of this is learned through critical discourse while reading and reviewing reports about science in the press or on the internet (Framework, 2012). Throughout the module, the teachers concerned themselves with learning how to structure discussions in their classrooms to relate scientific results to larger societal issues.
Lindsay’s experiences communicating her research results to a broad audience informed the discussions that occurred in her module. Relating scientific practices to larger, societal issues demonstrates to students how science informs policies and media that affect their everyday life (Rudolph & Horibe, 2015; Zeidler, Sadler, Applebaum, & Callahan, 2009). Feinstein (2015) mentions that “science educators have some interest in preparing students to understand and respond to the ways that science is framed in the media, as well as the fact that some politically sensitive issues are framed in terms of science while others are not” (p. 151). Lindsay leverages this mindset by recognizing that many teachers viewed politically sensitive issues as an authentic way to engage students in translating results between scientific and non-scientific audiences, extending how teachers can use the practice of *Obtaining, Evaluating, and Communicating Information* in their classroom. Concerning this Science and Engineering Practice when discussing socio-scientific ideas in the classroom, Lindsay and the teachers also recognized how the limitations of one’s understanding of the topic affects their authority when speaking about the topic. Given that many teachers have not experienced the authentic application of science practices as a part of a scientific community (Anderson, 2007; Capps & Crawford, 2013), the teachers expressed discomfort when thinking about discussing the broader implications of scientists’ work. Ford and Forman’s (2006) practices that demonstrate disciplinary authority could resituate the role of the teacher from being the arbiter of scientific knowledge to leading the social knowledge-construction process in their classroom. That, in combination with Lindsay’s suggestion of choosing topics that are interesting to the teacher and relating to the context of the school, could help de-emphasize the need for teachers to participate in research and situate the teacher as a co-learner, and guide as students refine their personal epistemology.

### 3.5.3 Byron — *Data Analysis, Error, and Systems Thinking*

In his module, Byron wanted to focus on the nature of scaling laws, both conceptually and mathematically. To do this, the module contained an experiment where teachers compared the length of femurs to mass and relative size of the animals they studied in the classroom and how these characteristics related to evolutionary shifts in anatomical features. He used this particular experiment in courses he taught to make his highly technical discipline more accessible to students from a broader range of majors. In the first activity, Byron and the teachers discussed differences in mathematical abilities between Byron’s and the teachers’ students as
they represented their data on graph paper, with Byron mentioning:

**Byron:** I’m into data science, I’ve been doing hardcore data science for 20 years, so I really have done a lot of graphs...I read them in a way that no high school student is ever going to do...I wonder if there’s an opportunity there to look at data graphics with them and see what I was thinking about...just to use plots and spend a lot of time interpreting them, having them really think about what they mean. After you did this a fair bit, maybe it would be easier for them. You’d probably have to do it quite a lot. [Byron, Observation 1]

In response to the teachers, he recommended that people with experience make their thought processes transparent to guide students through the graphing process. The conversation shifted from discussing the process of graphing data to mathematically analyzing the plot. Byron walked the teachers through finding a good fit through the data:

**Teacher 1:** They all want to do exponential. It’s the first thing.

**Byron:** It’s not crazy! I would try it too—figure out whether it’s a good fit, right?

**Teacher 1:** Right, but then we got to talk about what if the exponential function goes near zero and is that what the model is actually doing and then otherwise, they want to try fifth-order polynomials, which can fit anything pretty well. Both of them have their advantages and disadvantages, and I think it’s probably for what’s worked best for me is to do a little bit of both....

**Teacher 2:** Look at it, and then see... limit the functions they can use and say try a linear function or try a quadratic and see what fits best. See if it’s linear or not and then do it the other way, and then they can see that they have an exponent and how does that match the function that you picked.

**Byron:** I think that... you’ve got this tool that will fit any function you want, saying “play around in that space, is this or that a better fit? A better representation, a better model?” [Byron, Observation 1]

Through this part of the conversation, the teachers mentioned that students often jump to quick conclusions with simpler relationships when fitting lines and, when their fit does not match, jump to more complex, polynomial relationships. The teachers discussed the option of limiting the number of relationships available to students to help guide them. In contrast, Byron challenged the teachers to consider open-ended fitting, helping students to see both the power and limitations of the tool, eventually finding the simplest model that fits the data. From a disciplinary perspective, Byron’s idea suggests that this is like how scientists within his discipline handle fitting data.

The conversation between the teachers and Byron shifted to the nature of realistic data,
where there are deviations from the line fit:

Teacher: So most of the courses I’ve taught have been chemistry, so lots of calibration curves and line fitting, and I’ve done it at the college level, but a lot of them don’t understand why one group of their dots are really close to the line, and one group will have like four out of the five on the line and one will be way off and... they don’t understand why...those didn’t work and they don’t understand the concept of how the math works to connect it with concentration or the r-squared value.

Byron: That carries forward for a long time. I think that students who work with me in research, it’s there, after some time doing research, that they really start to get what are uncertainties in measurements and how do they really go into something like fitting a best line or... very sophisticated stuff. I wish there were more ways to get across the essential idea, focusing on what is really important. [Byron, Observation 1]

A teacher relayed a common issue when working with students on calibration data in a lab.

Byron empathized, discussing how it was common amongst even advanced students until they reach a certain level in disciplinary understanding. He then told a story on how error and statistical analyses played a major role in his dissertation project that ended up disputing claims made by other researchers:

We carried [the experimental equipment] all out there, put it in the desert, wired it all up, made it all work and what we found is the experiment that we built, we built to study something other people had said was true. They were all wrong. We did all of that labor to build this big, beautiful, carefully constructed experiment and what we saw was nothing when there should have been something there. So an experience like that makes you skeptical about statistics and, in one way that plays out when I work with students, is very often a student will start doing research with me and they’ll go off and be analyzing some data and they’ll find something really cool and they bring it to me and I have to have this conversation where I tell them that everything that’s exciting is wrong. It isn’t literally true, but it is 95% true. When you find something exciting, it’s exciting because it was a surprise. [Byron, Observation 2]

Relating with teachers’ concerns about representing data revealed a story about Byron’s practical perspective on how he engaged in the knowledge-construction process through his handling of outliers in data analysis. In the passage, he describes how the refinement of his personal perspective eventually contributed to the disciplinary perspective by refuting an accepted theory. While doing this, he communicated that outliers may have minute implications, such as misleading novices on directions of progress, or large-scale, and leading to research experiments based on misleading findings.
While Byron’s module focused primarily on scaling and measurement and their relationships to evolutionary shifts in organisms, he used these activities to launch greater discussions on interdisciplinary views of science. For instance, after introducing the activity in the first lesson, Byron states:

*The first big question is to ask about what science really is. I think high school students have a very strong sense that science is one of the four things we take every year...you take English, political science, and math...but that’s not much of a definition. It’s a slot in your schedule. They know there are different sciences that have different names, but they don’t really understand the relationship among them. Often, if you look at textbooks that are written in chemistry or biology or physics, they don’t use those other words very much. The biology textbook is about biology. It seems to be a big separation among the sciences. If you go back into history, you would find that at all times, up to about the beginning of the 19th century, science had one name, really...natural philosophy [Byron, Observation 1]*

Throughout his career, Byron worked to incorporate interdisciplinary perspectives in courses within his department. His perspective that science should be interdisciplinary by nature was catalyzed by working and supporting scientists from other departments, discussing university policies and perspectives on complex societal problems. He portrays this by discussing climate change with the teachers, stating: “Each discipline has a perspective, that’s kind of good for general approaches to solving problems, but complex problems like this need to have multiple approaches to be able to solve them.” [Byron, Observation 3]. He continues with “So, how are we going to solve problems like that? We need all the scientific disciplines involved. This is not a chemistry problem. This is not a law problem. This is…everybody’s problem, so interdisciplinary is the answer” [Byron, Observation 3]. In his personal perspective, applying an interdisciplinary lens to a wide series of problems that afflict society today demonstrates to the teachers a realistic perspective on how science can expand past educational settings to influence industry and broader fields such as public policy, health, and sustainability.

*Connections to the Science and Engineering Practices*

The Framework (2012) mentions that *Analyzing and Interpreting Data* can bring out the meaning of data through organizing, representing, and statistically analyzing data for use as evidence to make claims and guide future work. Byron centers his module on this practice by having teachers analyze femur data and leading them through line-fitting. Through this activity, Byron and the teachers discuss ways to introduce and support students in pattern-finding in their
105
data. The process of interpreting data includes *Using Mathematics and Computational Thinking*, specifically in using Mathematics as a “tool—both a communicative function as one of the languages of science, and a structural function, which allows for logical deduction” (Framework, 2012, p. 64). In Byron’s case, the teachers used a variety of mathematical functions to describe their data. This led to a discussion on how and when scientists use tools such as logarithmic plots to communicate transcendent properties, such as scaling laws in anatomical features of animals, with other scientists. Activities with simpler mathematical relationships, such as using linear models on logarithmic plots to determine exponential relationships, can model for students the thought process behind more complex relationships, such as Maxwell’s mathematical analysis of the behavior of electric and magnetic fields (as described in the Framework, 2012).

Byron’s research involved collecting and representing large sets of data. He alluded in the module that his prior experiences helped him to see patterns in data that other, untrained individuals would overlook. As a Ph.D. student, Byron spent a lot of time trying to reproduce findings from a well-known experiment within his field, only to consistently come up with evidence supporting contrary arguments. While completing a line-fitting activity and reflecting on error analysis with teachers, he used this experience to lead a discussion on error, outliers, and new findings in science. By doing this, he displayed the responsive nature of disciplinary epistemology (Duschl, 2008) and the researcher’s role in the validation process of new claims that other scientists put forth. After years of replication and failing to collect the data that supported the initial claim, Byron responded to the previous scientists by publishing his findings, pushing the discipline’s understanding of that topic. The Framework (2012) mentions error as an experimental consideration that should be reduced in classroom settings. Byron’s example demonstrates that error can play a more sophisticated role in the scientific knowledge-construction process, helping scientists identify and push boundaries from within their field. The example of error analysis also relates to a larger epistemological trait that Byron represented in his module: the interdisciplinary nature of modern science. His choice in activity reflects a recognition that he was presenting to an audience of individuals with diverse scientific backgrounds, both in terms of experience and discipline. As a result, the teachers discussed data representation and analysis and how it relates to their classroom context. This conversation inspired greater discussion about the intertwined nature of scientific disciplines, drawing resources from each other to solve complex societal problems. Byron wanted the teachers to
adopt a systems perspective (Hammond, 2017) to problem-solving, recognizing that while each discipline may have its view on how the Science and Engineering Practices are applied to problems in their field, these differences can spur on creative and previously unknown solutions to problems that affect all members of society.

3.5.4 Eve — Engineering Practices and Human Centered Design

Engineering can be viewed as a field where engineers conceptualize projects with specific variables in mind to make a functional, practical, and useful product. Since designing functional products requires technical expertise, many engineering classes focus on mathematical concepts and the application of these concepts to build a concrete prototype. Eve defines engineering design, from a disciplinary perspective, as the “application of technology to create an artifact that fits within the culture or context” [Eve, Member Check]. Using this definition to inform her teaching, she says that “my undergrad students have spent all their time with the technical aspects and it’s my job to say, “Engineering’s actually bigger than this. You can’t just design technical things in a box, you have to recognize the larger picture.” [Eve, Final Interview]. As a result, her personal perspective includes thinking about the culture and context for whom the project is meant and involving stakeholders in the design process to make a product that will be most useful for the problem and intended population. This process is called human-centered design, which focuses on meeting people’s needs. Eve states:

It (human-centered design) involves building a deep empathy so you understand where people are coming from. With the people you’re designing for, you generate a lot of ideas, you build a lot of prototypes, and you share those pieces...because they’re the people who are going to ultimately determine if your design is successful [Eve, Observation 1]

This part of engineering design is often overlooked, resulting in well-engineered products being brought into the field and remaining virtually unused because cultural factors were not considered during the design process. From a practical perspective, Eve strives to provide examples and give students chances to critique, problem-solve, and revise designs to gain a lens for considering social variables when completing projects in their future work. For example, she sets up her module by discussing a case:

This is from a study where they were looking at bio-sand filters that were developed for this particular valley in Haiti. The researchers went back and looked at the success of
these bio-sand filters, which were essentially developed and given to these communities as an optimized technical design. But, in their site visits, 47% of these beautifully optimized technical designs weren’t being used anymore...the bottom line that the researchers discovered was that they weren’t incorporated into the culture—the technologies, the education materials, the maintenance, the operation—because they didn’t take those features into account, the bio-sand filters were just pushed aside and the community operated as it normally did. Perfectly optimized system technically, but without contextual optimization, it failed. [Eve, Observation 1]

To accomplish the goal of representing the qualitative design aspect of her discipline, Eve combined an engineering design lab that was represented in the NGSS, designing a solar oven, with a lesson she teaches in the college of engineering where students develop interviews to learn about everyday experiences of stakeholders to inform variables to be considered in the product. She wanted the teachers to experience how an engineer might learn about specific variables (e.g., where and when the oven will be used and how much space it might take up) by interviewing people who will use the design. She mentions:

We’re going to use design ethnography methods, which is a collection of research tools to help us learn about users and contexts. . . Essentially, the idea is that this collection of methods is aimed at understanding experiences of everyday life of the design stakeholders. So, in our context, the design stakeholders are campers who need to cook with a solar oven. [Eve, Observation 1]

Eve then leads the class in constructing interview protocols and conducting interviews with people she invited to class, eventually helping the teachers analyze the interview data and discuss considerations that should be made when designing the solar oven. To aid the teachers in shifting the findings from the interviews into design specifications, she introduces a series of idea generation tools that her engineering students use on projects in the program. For example, a camper mentions the importance of limiting the oven's size (e.g., space and mass). Eve then introduces an idea generation tool where teachers take this design consideration and make it practical for their solar oven (e.g., use different materials, allow for unit flexibility). Discussing how Eve applies these tools in her classroom:

Teacher: I really like the [idea generation tool], but I’m wondering what the first lesson would look like where you brought those in?

Eve: I talk about idea generation separate from talking about human-centered design. If I talk about the design process holistically, I go through each phase and talk about best practices. So, I have a unit where I talk about idea generation. All
those different idea generation tools, we talk about how to use, and we practice in different product design contexts... When we develop the requirements, we develop the specifications; when we come to generating ideas, we’re not just looking at a blank piece of paper... Instead, we’re leveraging the idea generation tools that we’ve already practiced. [Eve, Observation 2]

Concerning her practical perspective, Eve discusses that her students regularly engage in practices that embody the consideration of contextual information in their design. She presents ethnographic interviews and the idea generation tools as ways in which practicing engineers influence design to cater it to the specific needs of the users.

Eve recognized differences between how engineering is portrayed in the classrooms and the actual practices of engineers. For example, she discussed how there is not a clear distinction between science and engineering in high school settings. Therefore, it is automatically assumed that students who thrive in science settings would function similarly in engineering settings. To get around this, Eve posited, “Instead of having to say, “Engineering connects to these science principles,” you could say, “This is what engineering is, now let’s explore some of those pieces. And then you could draw some connections to other topic areas, but it’s not just science.” [Eve, Final Interview]. By considering this, Eve argues that engineering can leverage skills that are not present in regular science classes, thus providing a more realistic view of the field. She also discussed with teachers a conception that engineering practices are purely technical, using the activity to show some of the qualitative components to the engineering field. Through this, she mentioned that “engineering design isn’t just about optimizing science principles. It’s not only about optimizing contextual principles either. Instead, it’s trying to figure out how you can balance both” [Eve, Observation 1]. The teachers reflected on these differences:

Teacher 1: That might be one of the first times in this program, in a science class, where I’m seeing something that was not normally taught in science. I thought [the ethnographic interview] was cool because, as a teacher, I always want to find ways to engage all my students, even those who might not have a natural affinity for science. Seeing the interview process and seeing what kind of things could be done there seems to help them feel like they contributed.

Eve: One of the things that I think engineers really like about the structure of the interview process is that it has a structure. A lot of times, when we’re in this STEM space, we think that the non-STEM things are just mushy... they don’t have rigor. When you represent—actually look at these technical details that are associated with structuring the interview protocol—people are like, “Oh!” It’s
not just you sit down and you say, “What do you want your design to be?” Right? There’s actually rigor that can make or break design success, and that has a big impact on engineers when they think about it that way.

Teacher 2: I just wasn’t used to having these real people come into the classroom and talk about their concerns for the product. It makes it much more real, and you’re integrating with society, and that is not usually necessarily the roles of engineers or scientists, and students wouldn’t see themselves in that lens, because it makes this whole process not necessarily about a project I’m doing for class, but you’re seeing the societal value for it. Some might not see it just as a classroom project, so it engages them more on a societal level.

Eve: I think design for engineers is that place where they can translate the technical stuff, that they spend most of their curriculum on, into how they can impact the world. There’s been a good body of research about the power of design in terms of how you can change the world, how can you change social situations, how can you serve or partner with communities where there are design opportunities that can improve ways of life. [Eve, Observation 2]

Connections to the Science and Engineering Practices

Regarding the differences between engineering and science, the NGSS promotes complementary views of success and explanations of epistemic practices between the two fields. For instance, the Framework (2012) mentions that “many scientific studies…are driven by curiosity and undertaken with the aim of answering a question about the world or understanding an observed pattern” (p. 47), whereas in engineering, “success is measured by the extent to which a human need or want has been addressed” (p. 48). Throughout her module, Eve advocated for human-centered design as a solution for the lack of consideration for user voice and context in the development of products. In both the design and implementation process, Eve sought to promote the differences between science and engineering by constructing her module around the engineering design process to model the practices of Asking Questions and Defining Problems, and Constructing Explanations, and Designing Solutions. For instance, she focused her activities around including the voice of users of a solar oven to optimize the design process based on contextual factors instead of a question about a phenomenon (e.g., how the relative size of femurs affects the scale of the organism). On a similar level, she instructed the teachers to utilize contextual factors to inform the product’s design instead of constructing a theory of a phenomenon (e.g., scaling laws for use between organisms). Eve emphasized the distinction between science and engineering by providing real-world examples of these differences and led
discussions on how teachers can better promote engineering in their classrooms.

While the Framework (2012) clarifies differences between science and engineering, many examples of how engineers apply the practices focus on the technical aspects of the field. For instance, in describing how engineers Analyze and Interpret Data, it mentions, “Engineers often analyze a design by…collecting extensive data on how it performs, including under extreme conditions” (Framework, 2012, p. 62). While the extensive use of data to inform design considerations is a major component of the work of engineers, Eve presents a counter-narrative that engineering is a balance between technical and non-technical characteristics. Qualitative tools, such as ethnographic interviews, are becoming more important as engineering design includes contextual and cultural factors. Eve’s module suggests that the types of data an engineer could consider while designing a prototype are expanding to include the user’s perspectives. This perspective is limited in representation in the Framework. For instance, most of the examples used when describing the types of questions engineers ask to Define Problems (Framework, 2012, p. 54) focus on the engineer’s perspective—what knowledge does the engineer possess to satisfy the design criteria? In her module, Eve wanted the teachers to consider alternative, non-technical perspectives that impact design specifications because oftentimes, the engineers’ culture and perspective can be limited. Eve addressed common stereotypes in the engineering field by introducing a human-centered design process, which focuses on the “problems they are addressing and potential solutions they design from the multiple perspectives of the people impacted by their designs” (Gunckel & Tolbert, 2018, p. 939). In doing so, she represented a phenomenon like what Gunckel and Tolbert (2018) present as a utilitarian solution to engineering problems, which considers solutions that improve specific subgroups of humanity.

3.6 Conclusions

This study is motivated by the need to develop a refined description of the NGSS Science and Engineering practices related to how scientists construct new knowledge. Often, secondary teachers learn the Science and Engineering practices without having experience applying them within a research context (Anderson, 2007; Capps & Crawford, 2013). Because of this, the practices are described in a general sense, focusing on modeling scientific activities that span across disciplines to help secondary teachers design activities where students learn scientific content through simulating the work of scientists. These classroom experiences further
representations of practical epistemology or the epistemological ideas students use to construct their own scientific knowledge (Sandoval, 2005).

3.6.1 Perspectives of Scientific Epistemology

This section discusses findings related to the first research question: how is scientific epistemology represented within the experiences of university faculty in developing and implementing an instructional module around their research? While the Science and Engineering Practices could be applied broadly between the faculty members, how they implemented the practices varied drastically between the modules. Professors have trained extensively to become full participating members in their specific scientific community through coursework, research, and representing their work to a broad audience. The process to become a full professor at a major research institution takes years of engagement with their discipline by becoming an expert in their respective field through contributions in the production and evaluation of knowledge. Throughout this process, faculty refine their practical perspective, or how their personal and disciplinary perspectives interact to influence how they engage with the norms and practices of how knowledge is constructed and organized within their discipline (Duschl, 2008; Kelly, 2012; Ford & Forman, 2006; Ford, 2008; Sandoval, 2014). As a result of this socialization process, faculty may focus on specific epistemological traits when asked to convey their research through instructional practice, which could be related to the dynamic connection between research and teaching mentioned in Robert and Carlsen (2017).

We found that faculty’s disciplinary perspectives varied drastically between their modules, as is captured by the content of the modules and the faculty members’ reflections on the design and implementation process as outlined in Table 3.2, the findings, and in the full cases (supplemental information). For instance, Michael wanted his audience to experience the lack of procedural structure characteristic of mathematical modeling of biological systems, which is a major focus of his discipline. To do this, he asked teachers to play with a physical model and determine how different variables shift data before asking them to characterize the model mathematically. As Michael described his teaching process, it appeared that research in his field contains an initial tinkering process where a researcher learns more about a physiological model and types of data that are produced before engaging in a structured thinking process to determine relationships, which are related to pre-existing models from literature in his field. This was
different from Lindsay’s module, which engaged teachers in collecting and analyzing environmental samples from around their community and connected the results to broader societal movements (e.g., climate change, Great Lakes algal blooms). This approach also resembles her research activities, where understanding the contextual nature of data and relating results to a broad audience are important components of Lindsay’s discipline. While the cases modeled *Asking Questions and Designing Solutions*, the norms and practices of the faculty member’s discipline informed which questions to pursue and how to explore those questions using the other practices.

To a similar degree, the process faculty used to design and implement modules emphasized their distinct personal perspectives of epistemology. Byron illustrated this, leading a discussion contrasting the differences between multiple scientific disciplines and their explanations of evolutionary shifts in organisms. In his initial discussion on the origins of science disciplines, Byron used the history of science to introduce his module to the teachers. This interdisciplinary and historical perspective relates less to his research in technical science (details omitted for anonymity) and more towards his college-level role, supporting instructors in developing curricular materials that are more conceptual and showcasing how disciplines work together to solve complex societal problems. This experience suggests that Byron operated out of a personal perspective that was separate from a disciplinary perspective related to his field of research. Faculty also represented their personal perspective from within a disciplinary representation of their field. An example of this is when Eve led discussions with teachers contrasting the technical nature often associated with engineering with human-centered design principles that she prioritizes when engaging in the design process. Throughout her in-class reflection and interview, she mentioned that her representation of engineering is not what people typically envision when they imagine her field. She used this distinction to lead a discussion with teachers on how her perspective could be used to design products for specific contexts and engage a wider variety of students in the engineering design process. Similar to what is mentioned in Hofer (2001), we found personal perspectives of scientific epistemology to be representative of the context, resources, and experience of the professor.

From within the cases, representations of practical epistemology emerged in two forms—the first involved faculty sharing their experiences as participants within the knowledge construction process within their discipline. For instance, Byron’s past experiences as a
researcher informed discussion about how errors and outliers are used in his field, helping teachers think about an important part of data analysis that is often overlooked. This relationship can also be seen in Lindsay’s case, where she disclosed her experiences communicating to a broader audience and how they affected her views on expertise in a discipline. In both examples, faculty members used specific events from their past disciplinary engagement to provide contextual information behind the scientific practices modeled in the activity. The second form involves faculty representations of disciplinary practices within the classroom. Eve and Michael utilized epistemic practices (Licona & Kelly, 2019), or activities and tools that engage participants in processes that model how knowledge is constructed in their field, to engage teachers in practices found in their research environments. For instance, Eve constructed a setting where teachers used ethnographic interviews to generate data on stakeholders and analyzed the data using engineering design tools to inform their modification of solar ovens. Similarly, Michael brought in a physical model of a biological system to generate data that teachers could analyze. Both Eve and Michael’s modules allowed teachers to engage in an activity using tools that modeled epistemic practices specific to their field. Through their practical perspectives, faculty considered which knowledge-construction practices were most important for their field and used their prior experiences to contextualize explanatory power on how the practices are applied in their work.

### 3.6.2 Relationship to the Science and Engineering Practices

This section discusses findings related to the second research question: How do the faculty’s experiences within the module relate to the Science and Engineering practices? The four cases in this study present instructional modules developed by university faculty that focus on showcasing tenets of their research to a group of secondary teachers. In the general sense, the modules mostly align with the Science and Engineering Practices (Table 3.3). For instance, all modules start by Asking a Question and Defining a Problem that inspired some form of Planning and Carrying out Investigation and Analyzing and Interpreting Data to Construct an Explanation or Design a Solution. All modules also contain some focus on Using Mathematics and Computational Thinking either explicitly through their activity, as when Byron discussed the processes of line fitting with the teachers, or latently, as when Eve discussed the representation of engineering in the classroom and advocated for a balance between technical and qualitative
design specifications. Similarly, some faculty members represent *Obtaining, Evaluating, and Communicating Information* through collaborative activities embedded within their module, such as when teachers worked with other groups’ findings to refine their mathematical model in Michael’s module and through responding to the interests of the teachers based on the content of the module, as when Lindsay focused on discussing and critiquing the political nature of scientific findings represented in popular media.

Noticeably missing from the modules is *Engaging in Argument from Evidence*. While the faculty members included some interaction with data through patternmaking and line fitting within their modules, the activities did not have teachers make and support claims about the explanations they constructed. One reason for this could be that claims are often generated and presented to the scientific community after a series of experiments uphold their driving claim. For instance, Byron mentioned that he spent years conducting and refining experiments that refuted other scientists’ claims before publishing his argument. We think that faculty members did not represent the argumentation of their discipline because the modules only focused on one experimental activity.

### 3.6.3 Summary

We think these findings are important for two reasons. First, offering opportunities for faculty to reflect on and portray their scientific epistemology in classroom settings could expose them to teaching practices that they can apply in their departments. We think that reflecting on their scientific epistemological values in the presence of educators could support faculty in designing and implementing reform-based activities for their classrooms. Second, collaborations between the scientific and education communities could offer insight into the disciplinary nature of the Science and Engineering practices, yielding concrete ideas on how to refine students' scientific epistemology. Professors are full participating members in their specific scientific community with distinct norms and practices. They also have unique lived experiences that inform how they participate, represent, and teach their epistemological values. We think these epistemological traits could be made explicit by studying how each scientific field applies the Science and Engineering Practices. Clarifying the differences between disciplines could help teachers without prior research experience design classroom experiences that more closely align with how researchers in their subject areas construct and validate new knowledge.
The results presented herein aligned with calls for in-depth, phenomenographical accounts of how college faculty utilize their research experiences to develop their teaching practice (Lund & Stains, 2015; Robert & Carlsen, 2017). We found that the partnership between practicing teachers and college faculty yielded a nuanced description of the Science and Engineering Practices within our structure. Professors’ scientific epistemology allowed for the authentic modeling of specific disciplinary practices in the classroom and their prior experiences in the knowledge-construction process contextualizing the practices. This work affirms the necessity of faculty trained in the disciplinary perspectives from specific fields of science and conducting education research from within disciplinary contexts. For instance, a discipline-based education researcher could use their common background with scientific researchers in their department to learn more about the norms and practices of their colleagues and construct representations of scientific practice while promoting reform efforts that align with professors’ views of their discipline. Furthermore, this partnership appeared to elevate the role of the teacher to allow collegial discussion around pedagogical topics, helping the faculty member reflect on their teaching practice—which is something they are less likely to encounter within their departments. Tenets of the interprofessional learning community could be used to create dynamic professional development experiences for both practicing teachers and college faculty centered on authentic research practice and considerations for its implementation in the classroom, allowing professors to engage with the greater education community to expand their understanding of teaching practices and learn how to implement these practices from within their contexts.

3.7 Acknowledgments

The authors would like to acknowledge the faculty participants for their time and resources while designing their modules and the preservice teacher students for engaging fully in the course. We would also like to thank Leah Bricker for her intellectual contributions to the course design process, analysis, and feedback on the frameworks utilized in the analysis. We are grateful to Jason Buell, Kathryn Hosbein, Danielle Maxwell, Field Watts, and Eleni Zotos for providing useful feedback on the writing at various draft stages.
3.8 Supplemental Material

3.8.1 Semi-Structured Faculty Interview Protocol

Describe your overall impression of the experience.
Was there anything about your experience that you found surprising?
When you were working with [the specialists] and co-planning what you would be doing, what was that process like?
What would you identify as the major challenges to the process?
What did you learn from working with participating educators?
If you were going to participate again, what would you do differently?

3.8.2 Descriptive Cases of Faculty Participants: Michael

Background

Michael is an experienced researcher and young professor in a highly successful, research-oriented department, and he has authored over 100 papers in his field. In his department, there is little impetus to design and implement novel approaches to teaching because the current structure has historically yielded success amongst students and researchers within his institution. He teaches technical courses where his students develop mathematical models and computer programs to characterize complex biological systems. This work is highly interdisciplinary in nature, pulling from physiology, computer science, mathematics, and biology to understand the variables of a system, how they relate, and how they affect the system. In this class, students utilize through classic papers in the field to reconstruct models for the intended system, reanalyze the data, and change the parameters to better understand the phenomena described by the models. The course is mathematical and computational in nature, so students need a general understanding of programming, biology, and mathematics to access the information in the course.

Similar to how problems are tackled in his field, Michael describes the process of teaching and learning as a problem of optimization. In this paradigm, teachers give students the tools and data necessary to build a model and the students must work through the variables and programming in a trial-and-error-like fashion. Reflecting on his usual approach to teaching, he mentions:
[The students] have some computer codes and they have the [materials] and they know how to access it, they get it from [the course management system], and they can download it and they can run it. Then we have some really simple questions, "What if you change this variable? If you modify this thing in this way, what happens?" Explore the model...play around with this device and see how it works. How does air come in, what happens to the pressure when air goes out, that kind of thing. Then we might have some kind of open-ended things and say, "Here's a data set, we want you to analyze this data set with this model. What do you have to do in order...to modify the model to capture some different phenomenon." There's a couple of us walking around the room looking over people's shoulders saying, "What have you done?" And trying to guide them through it. It's open ended. Sometimes people fail and then we have to say, "Everybody stop. Let's talk on the board about what we're doing." [Michael, Observation 3]

Since model construction is unique to the approach taken by the student, the teacher assumes a mentorship role to guide the student through their defined problem—effective teaching strategies are highly dependent on the students’ problems and their approaches, and it’s the teacher’s job, through trial-and-error, to learn how to guide the students to obtain successful models.

Planning
Michael was enthusiastic to build a series of high school lessons based on his research, but nervous since he has had little training in education and has rarely interacted with a community of teachers and specialists. Because of this hesitation, he relied heavily on the input of the specialist who was his contact during the project. Before the module, the specialist read key papers related to Michael’s field and visited group meetings to gain a knowledge of the research prior to designing the module. Both Michael and the specialist met twice monthly for six months to design the lesson, construct the model, and design student supports throughout the lesson. Commenting on Michael’s goal for the module, the specialist stated that “Michael was enthusiastic about representing complex ideas into approachable activities for teachers. He was thoughtful about how the pedagogy could be used in his own work, and he was optimistic and excited about getting laboratory model to collect data that could be used to form a hypothesis” [Specialist Interview]. To showcase the interdisciplinary nature of his field, Michael wanted to design a lesson where teachers developed a mathematical program based on data collected from a model of a biological system. To do this, he constructed a model lung with easily accessible materials which could be interchanged based on variables that the teachers wanted to explore. He then connected the model to a pressure sensor for the teachers to collect input/output pressure
data from the system. Through interacting with the model, Michael wanted participants to have access to a multitude of variables that they could manipulate in order to see their effects on the pressure into and out of the lung. The teachers would use Microsoft Excel to analyze data and build a mathematical model to show how the system variables were related. As a final outcome, Michael wanted the participants to change a variable within the model based on what they found interesting from the initial data analysis and to develop a mathematical model to describe the effects on the data, which would resemble the practices that are normal in his context. Michael mentioned that developing the mathematical program using Excel would be the primary area in which students and teachers would struggle, and he worked with the specialist in order to develop structures to ease participants through the process. Overall, he did not make a distinction between the contexts of the teachers and his own, making revisions that were similar to what he would consider while teaching his own students.

Instruction

The highly collaborative nature of the planning was evident in the initial facilitation of the class, as both the specialist and Michael had a role in launching the trajectory of the lesson. The lung activity was framed using asthmatic health conditions in order to engage the audience in a direct application of the model they were about to explore. During this initial process, the specialist led the teachers in developing structures and procedures, such as using think-pair-share to allow for discourse on participants’ ideas and establishing roles to encourage collaboration amongst group members, to help the experiment run smoothly while asking probing questions to check for understanding. Michael, on the other hand, functioned as a disciplinary expert, speaking when appropriate to clarify the connections to common practices in his field and how the model lungs related to a wide range of lung conditions. This teaching structure continued as the participants obtained their model lungs, explored how the model functioned, and identified the variables they could change in the process—the specialist tended to the pedagogical considerations (e.g., timing, questioning for understanding of relationships, course structure), whereas Michael focused on troubleshooting the model and offering insight to groups who were having trouble understanding their data. The lesson finished with the specialist leading a discussion on what variables were tested and how that affected the pressure; Michael added additional considerations and hypotheses that could yield interesting results.
Transitioning to the data collection and analysis process, Michael took a primary instructor role as the content of the lesson became highly computational in nature. The teachers collected data based on variables they were interested from the previous discussion and the results were analyzed using Excel to find patterns in order to develop a mathematical relationship. After the participants successfully collected data, Michael confirmed his hypothesis that teachers would struggle with using Excel to develop the mathematical model. Participants came to the course with a range of experience in Excel—any formatting and formula-writing issues were overcome fairly quickly by collaborating with their colleagues. A bigger struggle occurred when the teachers tried to establish the significance of the patterns and anomalies in their data, which revealed that many of them were having trouble changing and explaining the variables that were at play in the system. The course ended without resolution, with teachers working on their models and trying to manipulate the variables to better understand how they relate.

**Reflection**

In reflecting on the teaching process with the education professionals in the course, Michael mentioned that he tried to do too much too quickly, and that there was just not enough time to have the teachers apply their model, stating:

> I wanted to really close the loop and have them...do something with changing, adding, or subtracting something from the model or analyzing the data themselves. We just didn't have the time to do all that. [Michael, Final Interview]

He discussed that the struggle was inherently a part of his approach to teaching, where students generally exhibit hesitation when the materials and procedures are not as familiar to them. Regarding working with computer modeling systems in general, he mentioned:

> [The] last lab [I taught] I was building a very simple model, a simulation, and there's this very strange barrier to wanting to play around...I think writing formalized steps gets people engaged. I was like, "You can't break the computer. You can't break a virtual lab. Let's just try whatever you want." And they're like, "Okay. Like, are you kidding me?" We had a parameter, and I said, "What if we changed that parameter to square root of negative one."...This weird thing mathematically, right? Everyone was like, "No, no, no! I don't want to talk about that. That's getting way too complex"... [I said.] “Let's just see what happens. Let's type it and press run.” [Michael, Final Interview]
In this quote, Michael discussed how he could model for students the optimization process—that sometimes students need to try the process and experience difficulty to become more attuned to how virtual labs work. Reflecting on how he could address the problem, he mentioned that working through problems collaboratively, like what he experienced while working with the teachers, could make the mathematical modeling run smoother. He said:

*I think that collectively we use a lot of the ideas that you guys (education professionals) know how to use, but we don't have this formalization of structure to do it, and a collaborative way to really do it optimally. I think that we could go back and apply these techniques to it.* [Michael, Observation 3]

In response to discussions with teachers in the course, Michael suggested two changes that could be made to make the lesson more efficient: breaking down the lesson’s structure based on objectives and troubleshooting the model more thoroughly prior to class. He stated:

*The effort we've put into the devices still requires final troubleshooting to make sure everything works. I think that you probably have a lot more experience...so you have a really contained, focused thing (discussion) that's not going to go off into the woods too quickly....I think we would have to really break this up into either find little chunks of this, like just the modeling part, the mathematical computation modeling part, or just the device and what you can do with the device, and what you can learn. I think that's something that you guys can do, or we can do together.* [Michael, Observation 3]

Also, Michael reflected that he rarely thought about the difference in structure between secondary and post-secondary institutions, stating that “Having the actual teachers push back a little bit and say, ‘Oh wait a second, you can't do this in real class,’ and having the [teachers] sort of push back on the [faculty]…was definitely clearly valuable” [Michael, Final Interview]. As a result, he listened to the teachers’ suggestions for how to make the module more structured and efficient by adding written directions, including exemplar Excel models to guide students, and preparing ways to guide students through the types of cognitive dissonance that the teachers experienced during the lesson.

In terms of implications for his practice, Michael repeats that trying out new teaching practices is not a usual occurrence in his context. Thinking aloud about the process on how teaching normally occurs, Michael mentions:
It’s the standard kind of way we do teaching, which is we put a lecture together, and then we give the lecture...how do you teach something? The way you learned it is how you teach something. If it’s a math concept, you have a piece of chalk and you go through it on the black board...or if it’s an anatomy concept, you give a lecture with slides. A lot of time, half of the people ask questions if they have questions, but they’re more like clarifying questions. [Michael, Final Interview]

This reveals that Michael, similar to many postsecondary faculty, primarily draws from previous experiences as a learner in order to inform his current teaching practice. He continues by describing why teaching at higher education institutions occurs in this fashion, saying “I’m using the same labs from last year because I’m busy, and all of a sudden, it’s like, ‘Oh man! That’s next week!’” [Michael, Final Interview]. Both of these quotes reveal that thinking critically about pedagogical practice and its effect on student outcomes is not a focal point for faculty instructors, which may be a direct result of many faculty members viewing their primary role as a disciplinary expert who must focus on furthering the knowledge of their field. Through interacting with teachers, Michael mentions that “it’s probably fair to say that I learned that there are drastically different ways of doing things that might be better.” [Michael, Final Interview]. He appreciates when the teachers pushed back on his ideas and discusses that he would think more deeply about how he could create experiences that engage high school students while showcasing the interdisciplinary nature of his field. An example of this is below:

Teacher: I’m really excited about this philosophical question--is it a biological lab with an engineering focus, or an engineering lab with a biology focus? Connected to this comment are the needs, which is cross curriculum math science. I feel like all of our comments, and probably because many of us are teaching biology, but we’ve really been looking at this from a biology lens. How do we make this work in our biology classroom? But this is a very interdisciplinary thing, and so I’m wondering what you are thinking.

Michael: We were kind of talking structure a little bit about how we could make a whole sequence with these devices about physiology. It would be physiology and mathematics and engineering... There is no distinction. It's science, and it's interdisciplinary science. We could come up with a whole series of really interesting labs of course for high school students or maybe undergraduate students or maybe both, where they're taking measurements on themselves. Then when we're looking at the exercise capacity or breathing capacity or something like that and you're measuring it on yourself, and you're measuring it on your classmates, it becomes really interesting. We do it in lab and we say, "Look at me. What about you?" I can see high school kids really doing that and getting
engaged, but in just these devices and maybe a couple more things you could spend a whole year doing. [Michael, Observation 3]

This conversation shows how Michael relates the practices of his discipline to the teachers’ context in engaging students through illuminating the differences in structures between high school and post-secondary settings, providing a space where he is starting to explore how his activities may play out in different organizations. He mentions that doing modeling tasks on larger biological systems are interdisciplinary in nature and allowing teachers and their students to collect data on themselves could provide a pathway for deeper engagement. Overall, he has not had the opportunity to reflect on his own practice and plans to make it more of a usual occurrence within his context, mentioning in the final interview that “There are people that I've met at the school, and even in our department, that are interested in outreach in education. That's sort of getting the right conversation started. That's easy enough to do, talking to the right people” [Michael, Observation 3].

Conclusions

Michael presents a case where a content expert who is well-versed in disciplinary knowledge and practice is introduced to the practice of thinking critically about his teaching through interaction with both experts (experienced teachers and specialists) and novices (preservice teachers) in the education field. In many ways, his experience aligns well with early in-service secondary teachers, whose focus is primarily on curriculum development, how content is presented, and the day-to-day operations of the classroom. This outcome is understandable, especially when considering that the department in which Michael is situated offers little chance to develop, implement, and assess new curricula, and therefore provides limited opportunity to grow as a teacher. Interestingly enough, consideration of whom the content was being presented to and how the audience might interact with the content is not as much of a factor—Michael makes very few comments throughout the entire process in consideration of the teachers and their contexts. Another noteworthy point is that his version of introducing disciplinary knowledge to education professionals and students focuses more on building experiences to share with teachers. Opportunities for reflection are more reactionary in nature and are prompted in response to an event or interaction that occurred within the module. Through participating in this process, Michael gains exposure into how education professionals consider audience and use authentic occurrences as invitation to reflect on their practice.
3.8.3 Descriptive Cases of Faculty Participants: Lindsay

Background

Lindsay is an assistant professor in a field where communication and advocacy for implications of her lab’s results are emphasized to achieve funding and collegial support. Her work takes her to communities that are culturally different than the Midwestern town where her university is situated, and her research depends on forming relationships with these communities to gain support for her experiments. This part of her research also allows her to learn about how their cultures are shifting based on human influences on the environment in order to bring awareness to the scientific community. Her research takes traditional instruments that are developed in a controlled laboratory setting and brings them to extreme environments in order to capture data that is unique and highly contextual. Because of her role, she is viewed as non-traditional in her department and is well-respected for incorporating context, culture, and broader impacts in her research. Lindsay teaches introductory laboratory undergraduate courses. Her department is open to unique applications of laboratory research and allows faculty to develop courses that align with the content in traditional classes while introducing students to specific, research-oriented applications of the material. As a result, Lindsay developed a semester-long class that parallels an introductory laboratory course to showcase tenets of her research by including students in data collection and analysis. Despite having a structure for faculty in Lindsay’s department to apply novel educational techniques, there is little opportunity to discuss and reflect on the process of developing and refining curriculum.

Teaching, to her, is synonymous with advocacy. She views her classes as a means to help students see the broader applications of the content. Because of this, Lindsay tries to incorporate news articles, videos, and scientific papers in her classes and asks students to reflect on how these sources relate to important topics in their lives. For example, in introducing a topic like climate change, Lindsay mentions:

*I often get asked whenever I'm talking about something like this: “Okay now you've told me these things that are happening and disease will spread and storms will increase, so what are we going to do?” This is really depressing, and I feel like there's nothing we can do about it. I found this nice video, I think this is a National Geographic video that's about climate change solutions, things that individual people can do, research that's happening. They talk about smog eating concrete, roads that you drive on that create electricity and all sorts of really*
exciting things, some of which are being tried out in Europe. I think it's a nice follow up to this question. I think it's like six minutes of your time, and I would encourage you after class to look at that. [Lindsay, Observation 1]

She also believes that scientists have a duty to connect to the broader community and incorporates some part of the communication process (e.g., poster presentations, discussions) into her classes. She mentions:

I think there's a big responsibility as a scientist to communicate. If you don't write a paper about your stuff, it doesn't exist...I think there is an ethical responsibility to try to help with the fact that, and I don't know if you can look it up, but I heard one time at a science communication thing that it's like twenty percent of the US adult population is science illiterate. And so, to me that is a huge problem. And that's where outreach comes in... To me, this was a responsibility that is, in some way or another, a place where we can give back. [Lindsay, Final Interview]

As a result of this imperative, she wants her students to assess validity of claims in a wide variety of sources, and therefore provide opportunities to discuss how scientific data gets interpreted in different contexts. For instance, in the workshop, she discusses that claims made in a popular science magazine can look vastly different when compared to the original claim from the peer-reviewed, primary source. It is her goal to help her students evaluate which sources provide the most valid and necessary information relevant to their needs.

Planning

Lindsay has conducted a small amount of education work through outreach and education research activities related to her discipline. Given her inclination for these things, it was an easy decision for her to participate. She was eager to receive feedback from people who are familiar with educational practice on the curriculum she developed for her classroom. To develop the module, she collaborated with education-oriented graduate students in her lab to create an experience where the teachers would engage in the process of thinking like a scientist. In her activity, teachers selected areas in their contexts to collect environmental samples and analyze them using an activity that was an important technique in the introductory laboratory course that she taught. She also hoped the technique would be applicable in a traditional high school setting. The specialist working with her mentioned:

She felt comfortable with the science and adapting the science. She felt less so with the pedagogical aspects, and it seemed as though she would benefit from
Lindsay wanted her module to have a clear connection to the broader impacts of her research, and sought to infuse discussion on current news, science articles, and source validity while learning about the scientific technique. This was applied in a greater conversation about discussing potentially sensitive topics that could have political implications, such as climate change, to high school students using easily accessible sources so that students could come to informed decisions. While she mentioned that some participants may struggle with the technique, she was most interested in constructive feedback that the teachers could give in order to make it more accessible for students.

Instruction

Lindsay used the initial lesson to ground the course within the broader impacts of her research. After introducing herself and the nature of her research laboratory, she led an activity where teachers discussed evidence of human impacts on the environment by contrasting differences between public perception of science versus actual science. She then told stories about instances where she, among other scientists, interfaced with the public in order to communicate her results. This led to watching pertinent news videos that were more specific to the scientific research that informed the activities in the module. The teachers were excited to ask questions about both science and communication and asked for insight about ways high school students can be engaged in these conversations in a respectful manner. Once this discussion was complete, her graduate student presented a previously collected set of environmental data based on locations around the town in which the university was located and the teachers were asked to find patterns and trends. They then discussed why these patterns and trends were present and thought independently about which locations might be most interesting to study for the activity. After sharing their ideas, the teachers created hypotheses and selected locations in their own contexts to collect data that they would then analyze in a subsequent class session.

The teachers collected samples at their planned locations and analyzed the data in lab. Lindsay and her graduate student were very perceptive to the needs of the teachers, asking clarifying questions about them (e.g., prior experience with the technique, clarifying the classroom context they would adapt to) in order to determine how best to introduce the subject and how this technique could apply to a variety of subjects (e.g., chemistry, biology, physics).
Many of the experimental techniques ran smoothly because of these initial considerations, allowing time for Lindsay and her graduate students to troubleshoot the technique, ask questions about the content, and get to know the teachers’ interests. They also provided structural backing to the class, noting time remaining and addressing common concerns amongst groups as necessary. As the teachers finished analyzing their data, Lindsay set up a collaborative data table through Google Sheets where teachers shared their results and hypothesized about the patterns they noticed with their group. The shared data sheets also allowed the facilitators to know who had completed the data analysis in order to gauge when to move on with the lesson. Once all groups completed the analysis, teachers discussed the patterns they noticed and explained possible mechanisms for why those patterns existed. Lindsay and her graduate students also participated and offered insight from a disciplinary perspective, especially for when anomalies were noticed. To wrap up the experimental section, Lindsay and the teachers discussed alternative applications for the technique, noting that many of the teachers had questions about other ways the technique could be applied during the investigation.

An article contrasting the real-world practices of the scientific community and public perception of how science is taught in secondary education was assigned in between sessions to inspire conversation on how this discrepancy can be addressed in the teachers’ classrooms. The ensuing discussion led to the sharing of a wide range of resources from universities, national organizations, and databases in order to solicit student discussion of actual scientific results in order to compare to how the science is presented on more popular news outlets. Much of the discussion centered on how the norms and practices of the scientific community can be modeled for students in order for them to participate in the process while looking at actual data from a research laboratory. The module concluded with Lindsay summarizing the main points of the lesson, reflecting on the data analysis process and the teaching process for her, and offering ways to better translate the material to a high school context.

Reflection

The reflection process began with a conversation between the teachers and Lindsay about how the teachers could best represent scientific authority despite not being an expert in the field. Many of the teachers felt that they were barely qualified to find discernable data and present it to students as an authority figure, let alone lead a discussion with a meaningful outcome. One part of this conversation is detailed below:
Teacher 1: *What I was thinking of, as far as informing yourself, is that you have to know what you don't know. Right? So, for this whole (environmental) issue that we're talking about, do I know what's going on or not? Because that's when you know you have to look up something. So, I guess an issue that I have is what do I need to know? Or like, when do I know I don't know something? How do you know that you don't know something until it comes to you?*

Teacher 2: *What I was going to say, when I try to inform myself, I try to think about in what way might I create access points for my students to understand things. Because a lot of students distrust science. It's this big authority that you can't do away with and they can't really gather or trust. And I guess, I'm looking at this and I'm wondering what tools do they use, and how do those tools work? I just have to tell the kids and they have to trust me. For me to speak about...authority, I gotta understand how those tools work as well. So, there's a lot of deep stuff here or rather stuff that we should cover in the science class. But if we can't get to it, I don't understand the tools that are used, how the data is collected, how it's analyzed, what models you make? So, it's tough. And at the end of the day, I want them to make their own decision.*

Lindsay: *So, in science, you feel like you can't talk about that because you don't know about that. And I would say that at least most of the time, at least from what I've seen, looking at undergraduates and graduate students, most people don't get to the point of understanding in an area what they don't know, until about third year of grad school...I bring that up from the standpoint that you have to make decisions about what is enough in order to teach that area and to bring something meaningful to the students because otherwise if I wanted to be cynical, I'd say well then that means none of us are qualified to teach high school. You know? We haven't gotten a PhD in every single topic that's taught [Lindsay, Observation 3]*

This discussion revealed a moment where the teachers discussed their insecurity about working with and conveying disciplinary knowledge to students due to their lack of expertise in the subject, and Lindsay needed to relate the contexts of the teachers to how a novice navigates becoming familiar with the discipline. Lindsay artfully engaged with the insecurities of the teachers by disclosing her own, affirming that it is difficult to convey content in an authoritative fashion even when you are moderately comfortable with the material. She told a story about how she functioned on a panel as an expert but felt like she could not contribute because the topic was on a different subdiscipline within her field (quote omitted for anonymity). She related this anecdote back to the classroom by saying:

> *So, if I were you guys and I were thinking about how could I teach this in the classroom and one of the things that I would want to do is engage in the local*
area. Think about what's around you…. since we're near the Great Lakes. How do we think about...the Great Lakes? Well, then you can think about algal blooms and about how algal blooms are increasing in the Great Lakes. Well, that impacts the Toledo water supply. You can talk about biology. The algae, there's many different opportunities…. But, to me, if you were going to have to teach it. I would think about what are the things you feel comfortable with? What are you interested in? And what's nearby that the students can connect to? And take it piecewise and figure out what do I know about that one topic, rather than worrying about everything. Because doing that, at least for me, would be very, very scary. [Lindsay, Observation 3]

Her potential solution for the teachers had nothing to do with the content presented in the lesson. Instead, it captured an important point when considering developing lessons that contain research questions—that the teachers should look into problems that are pertinent to their context and focus on something in which both the teachers and their students are interested. Another concern raised by the teachers was the number of concepts covered in an application lab, and that it might be difficult to structure for their students. In response, Lindsay mentioned:

They're students that are going into science and engineering, so they have some affinity for it. They just get nervous when they get into a new application. Which is why I think it's even more important to give them new, different applications than just, “My teacher told me this, or I read this in a textbook, and I memorized it, and I don't need to apply it anywhere else.” Because as soon as the application comes in, then all memory is gone. [Lindsay, Observation 3]

In this quote, she reiterated the importance of incorporating scientific practice into the secondary classroom, as it helps students see the broader applications of the scientific field. The class then spent the rest of the discussion brainstorming ideas for how to structure the material in order to incorporate more of this frame of thought into the teacher’s contexts.

In reflecting on her own experience with teaching, Lindsay mentions that “I've never taken an education class in my life...Except for the one-day teaching academy, which I think I had a wake-up call where you realize all of a sudden that you are old and all of the students are learning in ways that you didn't” [Lindsay, Final Interview]. Because of this, she appreciated a setting where she could try something new and receive feedback—which was a new experience for her. She mentioned:
I think that the biggest thing to take away from it is how much your audience changes that whole experience...I really enjoyed it as a collaborative thing where it didn't feel like I'm just teaching these people. It was people that were here to experience this and learn, but I knew that I could ask them for feedback and they're going to be really honest with this on the application. It is like it's more of an equality (between teachers and students), which was really nice. [Lindsay, Final Interview]

Lindsay recognized the importance of gathering feedback from people who are knowledgeable about teaching and was beginning to recognize the importance of the input to her own teaching practice. Much of the feedback from teachers focused on how the course was introduced and how the problem was set up, with many of the participants excited to find problems that were local to their context to analyze with students. In reflecting on how she would shift the next iteration of her course, Lindsay said:

Yeah. The thing we're going to have to do next fall is to pitch it better from the beginning. Make it clearer to them what the whole goal is, what the science questions are. The problem is you pitch it well in the beginning—and that's good—but they don't know any of the content in the beginning to understand what that is. So, I would refer to things, but they didn't really, truly, fully understand it until the end. And I need to make that clearer, or we need to make that clearer in the very beginning. [Lindsay, Final Interview]

By building the imperative earlier, she could draw upon student’s excitement and interest and refer back to the goal while they are learning content and techniques that are important for data analysis. In response to how the course module structure could be applied, Lindsay mentioned that she could have benefitted doing something like this as a young professor trying out new course material, because it “would be a nice way to demo something, learn, get feedback, see if you want to do it,” because “there's nothing in the department to help us with that…” [Lindsay, Final Interview]. She mentioned that watching the specialist interact with the teachers was eye-opening, and that she could learn a lot by observing the education community interact and work through problems of practice.

Conclusions

Lindsay’s experience modeled that of someone who wished to improve on teaching practice, but has not had time, space, and available resources to do so. Participating in this experience allowed her to think outside of her norm and relate her
material to an audience that was much different than the students she usually teaches. Because much of the course had already been designed, she modified prior material with the intention of receiving feedback and reflecting on how the feedback would shift her curriculum. This focus allowed her to spend more time interacting with teachers, attending to their needs, and creating materials that would relate better to their context, ultimately increasing participant engagement through the discussion. While creating the environment for teachers to engage in conversation about how to convey the practices and norms of her field, it was apparent that she learned more about struggles that secondary teachers face while structuring complex activities and ensuing student discussion on potentially controversial topics. She also experienced how teachers work together in communities of practices to determine instructional problems that are localized to their context and to brainstorm potential solutions for upcoming lessons. For the teachers, gaining an understanding about how scientific authority is established and projected based on the intentions of sources helped build discourse in the module about how to frame discussions of the norms and practices of the scientific community with their own students. Also, teachers hearing firsthand from a practicing scientist how she framed these discussions with her own students showcased how scientists collaborate to make authoritative claims and how they communicate amongst themselves. In this case, an interface between disciplinary knowledge and teacher learning was apparent, appearing to be a dynamic experience for all participants. While the research activity learned in the module is certainly an important concept in Lindsay’s field, the primary objective of this lesson seemed to focus more on creating platforms for students to engage in learning the norms and practices of her field. This included discussing trends and patterns in data and critiquing resources to help students become more aware of the responsibility of scientists to communicate their results.

3.8.4 Descriptive Cases of Faculty Participants: Byron

Background

Byron is a distinguished professor who has contributed to research both in his discipline and in education throughout his multi-decade tenure. His department serves a wide range of students from other disciplines in its introductory courses. Throughout his career, he has served
on committees to restructure introductory courses in his department to make them more engaging and relevant for the represented audience and he has made his highly technical discipline more accessible to a broader range of students. With this in mind, he has developed a suite of courses that are more conceptual in nature, exploring the connections between his and other disciplines to showcase the interdisciplinary nature of modern science. Byron teaches technical higher-level courses along with more traditional introductory courses in his department. Because of his experiences, Byron’s responsibilities have expanded from solely teaching and research to include leadership roles at the college-level so that he can influence the academic environment throughout the university. Byron also holds an official appointment at the School of Education to help build the culture of discipline-based education research in other departments by mentoring younger faculty members as they develop their own research groups.

Byron balances his classes between the history and philosophy of scientific thought and current practices in science, stating that “there’s this idea that somehow between Aristotle and now, things broke apart into disciplines and started to seem like they were really separate from one another” [Byron, Observation 3]. As a result, the different scientific disciplines adopted norms and practices that helped solve problems related to their field. He mentions, “there are strengths to that, the fact that it enables us to go really deeply into one of these subjects and really understand it well, but…sometimes we have to bring these things back together” [Byron, Observation 3]. In terms of student engagement, Byron realizes that most of his students are not going to major in his discipline, so he expands the scope of the course to engage in complex problems where the solution might require a collaboration between a multitude of disciplines. Relating this to an issue like climate change, Byron states that “Each discipline has a perspective, that's kind of good for general approaches to solving problems, but complex problems like this need to have multiple approaches to be able to solve them.” [Byron, Observation 3]. He continues with “So, how are we going to solve problems like that? We need all of the scientific disciplines involved. This is not a chemistry problem. This is not a law problem. This is…everybody's problem, so interdisciplinary is the answer” [Byron, Observation 3]. An interdisciplinary lens can be applied to a wide series of problems that afflict society today and introducing students to this can offer a realistic perspective on how science expands past educational settings to influence industry and broader fields such as public policy, health, and sustainability.
Planning

The common structure for science courses in secondary education embodies the mindset that traditional disciplines are separate from one another. As a result, teachers and students engage with discipline-specific content using discipline-specific problem-solving strategies and are rarely afforded the opportunity to learn with a cross-disciplinary perspective. In response to this, the NGSS introduced crosscutting concepts to encourage the development of skills that would be useful in applying interdisciplinary approaches to science. Byron, with the goal of showcasing some of these crosscutting concepts, modified a lesson that he taught in which students think about scaling and measurements, materials, and how they apply to biological concepts such as evolution and anatomy. Describing the philosophical goal of his lesson, he states:

*It's hard to not think there's a big divide between living things and non-living things because living things just seem to do all kinds of stuff that non-living things never do. So, it's really easy to perceive that divide. I want to challenge that divide and make people think about life as a physical thing... We want to consider this question in the class: is biology really a physical science? Or is there something about biology that is different from physical science? [Byron, Observation 1]*

Byron was comfortable with planning lessons in this mindset, and as a result, relied very little on the specialists during the planning stage. He knew from previous experience that working with logarithmic graphing would be a challenge for most students, and therefore was interested in how the teachers would structure logarithmic graphing within their own classrooms for their students. Since he came to the workshop with a suite of lessons based on this topic, he wanted to gauge the audience and their needs based on contexts and select from his past work before making his plans concrete.

Instruction

It was apparent from the start of the module that Byron valued his students’ diverse assortment of backgrounds, as he spent a good portion of time getting to know the teachers and their interests. During this time, he related to them as best he could, posing comments to their views of science and math, hobbies, and teaching contexts, stating during his introduction:

*[The specialist] gave me a very generous introduction. Lots of nice things that she got to say about me. I would like to hear a little bit about each of you before we start—both because we have plenty of time to do that and because it will help me*
to modify and adjust a little bit what we do while we're here. So, could you please each tell me who you are, something about where you're from, something you like to do maybe outside of your professional life, and then, use one word to describe your relationship with [the represented discipline]. So, I want to get a sense of your level of comfort. [Byron, Observation 1]

By spending time building relationships, the participants seemed more open to conversation amongst themselves and with the instructor. The class was then prompted to move into a discussion about the history of science, the origins and differentiation of the various disciplines, and how practices and norms of scientists differ between the disciplines and even subdisciplines within a single discipline. He set this conversation up by discussing:

*The first big question is to ask about what science really is. I think high school students have a very strong sense that science is one of the four things we take every year...you take English, political science, and math, whatever...but that's not much of a definition. It's a slot in your schedule. They know there are different sciences that have different names, but they don't really understand the relationship among them. Often, if you look at textbooks that are written in chemistry or biology or physics, they don't use those other words very much. The biology textbook is about biology. It seems to be a big separation among the sciences. If you go back into history, you would find that at all times, up to about the beginning of the 19th century, science had one name, really. It would vary at different times, but it was basically one name was commonly used. That was natural philosophy—It was learning about the world in a naturalist way. Thinking about it as a natural thing. So, Aristotle would certainly have talked about everything in kind of thought, really. From ethics to biology. [Byron, Observation 1]*

Once these distinctions were classified, Byron shifted the class towards thinking in an interdisciplinary fashion, focusing on the differences in ecological systems between winter and summer and how the traditional disciplines (chemistry, biology, physics) would frame how plants shift through the seasons. He then expanded this to how these traditional subjects would approach describing evolutionary shifts in the plants, ultimately leading towards scaling—how volume, surface area, and mass interact with environmental variables to shift the course of anatomical structure in organisms. After introducing the context, Byron described the nature of scaling laws, both in a conceptual and a mathematical manner. This was aided by working through a log-log plot, which is a tool used to communicate the mathematical relationship of conceptual scaling when orders of magnitude are shifted in measurements. To make this plot,
scientists take measurements of two variables of an object and plot the results, creating a line of best fit to represent the appropriate scaling law. He then solicited teachers’ opinions on how to make this mathematical concept more relatable to their students, discussing pedagogical scaffolds along with engaging applications. The introductory session was concluded by extending the material to brainstorming how different ecological factors affect organism anatomy and how this is reflected in popular media.

After setting up the context and background, the class began a lab where the teachers conducted a scaling analysis of femur bones from a variety of animals. The participants had access to measurement tools and could compare variables such as length, diameter, mass of animal, and bone density. Throughout this process, Byron circulated around the room, engaged in discussion about which variables could yield interesting results and offered insight on the analysis process. In order to ease anxiety about the mathematical relationships, Byron asked the teachers to graph their log-log plots by hand in order to stimulate mindfulness about units, scale, and point placement. Confusion about relationships and line fitting set in amongst the teachers, and Byron intentionally directed conversation between groups in order to gain consensus on how to move forward with the data. After each group measured 3 or 4 variables and determined scaling laws, the teachers shared their findings with the entire class and discussed reporting error and reliability, specifically for how to discuss findings with students. Byron gave disciplinary insight when appropriate, but mostly allowed the teachers to discuss amongst themselves.

To wrap up the course, Byron introduced a common demonstration that showcased scaling laws and described what he perceived as the most engaging components of the activity for his students. He then challenged the teachers to collaborate and come up with their own version using materials that are readily available and safe for students to use. The teachers collaborated with each other and amongst other groups, and then had a group discussion to offer their thoughts. After the discussion, Byron described the interdisciplinary nature of scaling laws, using it to outline how such an approach could be a solution to larger issues that affect society. He used the example of how departments at the university are collaborating to find solutions within their context in order to make operations more sustainable. He then asked contextual questions about how departments like the school of social work and the school of education could contribute to this goal, which stimulated conversation about broader issues such as climate change, poverty, and public health. Throughout this, he solicited ideas for how these topics could
be introduced in schools to make students aware of the nature of science work that is conducted in research laboratories. The conversation finished with Byron recommending websites and scholarly social media resources for teachers to explore actual research that is occurring in reputable labs.

Reflection

Byron approached the module in a collaborative manner, as he was looking to gain insight on the participants’ contexts in order to present the material in a way that would be useful for a secondary setting. He expressed this in the beginning of the module by stating:

I would actually like to lean on you more and ask you to help me think about ways in which you might build demonstrations or have students build demonstrations of some of the phenomenon we're going to talk about here today [Byron, Observation 1]

Byron focused on a topic in which he was familiar so he could offer a well-thought-out lesson that the teachers could make their own. Reflecting on the lesson, he stated that:

It's a level of preparation or familiarity which I think high school teachers rarely get to have unless it's a really core piece of material they've been teaching for a long time. You don't get to spend hours and hours on anything, much less a niche thing. [Byron, Final Interview]

By having a more polished lesson, Byron was able to focus on feedback from teachers for how to better relate more technical components of the lesson, like plotting and line-fitting, to students in order to smooth out the process for his own classroom. One reflection on this comes from the specialist who worked closely with Byron, who stated that “they used graph paper rather than Excel. He anticipated the issues they might have with plotting the data and was prepared for those and used them in his lesson and discussion.” [Specialist Interview] Byron used his prior experience teaching the lesson to inform how he should present the mathematically difficult material in this alternative context, which included refraining from using Excel to analyze the data to minimize smaller mistakes that students generally make. In the reflection with teachers, this modification was noted:

Teacher: I just think that students don't understand what the values actually mean, like the boxes themselves what they represent. That's just the problem I keep bumping into. In addition to what you just said, students will anticipate 1.58 next to 2.51, they don't do that.

Byron: I'm into data sciences, I've been doing hardcore data science for 20 years, so I really have done a lot of graphs...I read them in a way that no high school student
is ever going to do...I wonder if there's an opportunity there to look at data graphics with them and see what I was thinking about...just to use plots and spend a lot of time interpreting them, having them really think about what they mean. After you did this a fair bit, maybe it would be easier for them. You'd probably have to do it quite a lot.

Teacher: One of the things that surprised me when I started teaching is that the number of students who would actually go and plot... and put equidistant the data points, so they would put 1.58 on the x-axis, the next tick mark is 2.51, the next tick mark is 3.98. I was so surprised that they did that, but it happens over and over.

Byron: So really fundamental kind of different view about what this means. I'm making a list of these points, not that spacing means something. I'm just making a list of them. They're kind of producing a table, yeah. [Byron, Observation 1]

In this interaction, a teacher voiced a concern about how their students struggle with representing proper scale and understanding the true meaning of the values. In response, Byron was empathic and hypothesized that more exposure to graphs—and more mindful analysis—are a means to help the students overcome this barrier. As the teacher disclosed more specifically that the students use equidistant spacing while graphing, he broke the task down into a simpler component, suggesting that students present their data in tables to be more mindful about where they place their points. The conversation then moved towards the more complex task of how students approach line fitting, which is disclosed below:

Teacher 1: They all want to do exponential. It's the first thing.
Byron: It's not crazy, I would try it too--figure out whether it's a good fit, right?
Teacher 1: Right, but then we got to talk about what if the exponential function goes near zero and is that what the model is actually doing and then otherwise, they want to try fifth order polynomials, which can fit anything pretty well. Both of them have their advantages and disadvantages and I think it's probably for what's worked best for me is to do a little bit of both. Before introducing this... 
Teacher 2: Look at it, and then see... limit the functions they can use and say try a linear function or try a quadratic and see what fits best. See if it's linear or not and then do it the other way and then they can see that they have an exponent, and how does that match the function that you picked.
Byron: Right, so let them look at it on a linear scale.
Teacher 2: Then they can see that the slope of the log-log plot gives you the exponent, and then have them see what did you find most helpful? What process was more helpful for you?
Byron:  *I think that narrowing the problem and saying, instead of the fact that you've got this tool that will fit any function you want, play around in that space to say, is this or that a better fit? A better representation, a better model?*

Teacher 1:  *And saying that the simpler model is more useful, because otherwise you have too many parameters and that's not good either, so the simpler the model, the better. [Byron, Observation 1]*

This interaction represented the collaborative conversations that occurred between Byron and the teachers where a complex topic that was a perceived struggle for students that underwent troubleshooting. In this particular case, the participants considered the process of limiting variables while creating lines of best fit while keeping the goals of the lesson in mind. Reflecting on the process, he mentioned:

*I knew coming into this, for example, that anything to do with any kind of log plot is really hard for everybody, frankly. Even people who use them all the time aren't typically that good at it. I think some of the people in the room have enough trouble manipulating sets of numbers into even simpler graphs...This is an idea that if you wanted to talk about scaling with students, you need to spend a little time to make sure they get it. This is one of these things where scientists get used to making things like log-log plots and they just do it, and really, it's not that hard, but you really have to stop and spend some time on it if you want people to understand it. It isn't the most difficult thing, but you know people have forgotten everything about logs and you have to remind them, and anyway I thought I would slow down a little bit. [Byron, Final Interview]*

Byron recognized how familiarity with a particular technical topic could influence the speed at which he teaches the subject. Working with the teachers offered Byron the opportunity to understand the difficulties teachers face when conveying information to students who have little background in the subject. Another area where this surfaced was a conversation about discussing outliers in data sets with students:

Teacher:  *So most of the courses I've taught have been chemistry, so lots of calibration curves and line fitting, and I've done it at the college level, but a lot of them don't understand why one group of their dots are really close to the line and one group will have like four out of the five on the line and one will be way off and... they don't understand why...those didn't work and they don't understand the concept of how the math works to connect it with concentration or the r-squared value.*

Byron:  *That carries forward for a long time. I think that students who work with me in research, it's there, after some time doing research, that they really start to get what are uncertainties in measurements and how do they really go into something like*
fitting a best line or... very sophisticated stuff. I wish there were more ways to get across the essential idea, focusing on what is really important. [Byron, Observation 1]

A teacher relayed a common issue when working with students on calibration data in a lab. Byron empathized, discussing how it was something that is common amongst even advanced students until a certain level in disciplinary understanding is reached. He then continued by telling a story on how error analysis and statistical analyses played a major role in a research project that relied on data from another source:

*We carried it all out there, put it in the desert, wired it all up, made it all work and what we found is the experiment that we built, we built to study something other people had said was true. They were all wrong. We did all of that labor to build this big, beautiful, carefully constructed experiment and what we saw was nothing when there should have been something there. So an experience like that makes you skeptical about statistics and, in one way that plays out when I work with students, is very often a student will start doing research with me and they'll go off and be analyzing some data and they'll find something really cool and they bring it to me and I have to have this conversation where I tell them that everything that's exciting is wrong. It isn't literally true, but it is 95% true. When you find something exciting, it's exciting because it was a surprise. There are two ways you can have a surprise. One is there can be something really new that no one has seen before and the other is you screwed up. So, when you see a data point that doesn't fit, it's a surprise, it's like what's going on there, probably you made a mistake, maybe it's real but it's perfectly reasonable that if this point is off the line, you should go back and look at that again. It might be real. You might look and see this and say this is something else. [Byron, Observation 2]*

This sort of interaction captured Byron’s willingness to relate to teachers’ context while portraying the disciplinary practice of analyzing error in science. In doing this, he communicated that working with outliers has implications that may be minute, such as misleading novices on directions of progress, or large-scale, such as leading to research experiments are conducted based on misleading findings. These types of stories could be translated easily to students as they work on their own data in order to incorporate disciplinary knowledge into the classroom.

In terms of his own practice, Byron came to the classroom with years of experience teaching lessons based on what he presented. He reflected:

*Every time you teach you learn things that effect the way you teach. This is a couple hour experience on the top of 10,000 hours of other teaching, so the idea*
that this would lead to some huge change is probably not realistic. But everything leads to small changes. I guess I would say that the biggest kind of thing is an increased understanding and sensitivity to an audience that I don't interact with that much...probably the changes in the way I would interact with an audience like this would be larger if I went back and did this again. [Byron, Final Interview]

One consideration that emerged centered around keeping the lesson more open-ended from the beginning. Byron mentioned that “I prepared a bunch of material when really, I should have left it lot more open. We managed to transition it that way…” [Byron, Final Interview]. He went on to say:

After having been there a little while, it's a little clearer what's possible to do and what the people are like and what they're ready to do. I know that when I go into a new kind of environment, new kind of teaching environment, speaking environment, or whatever it is, the opening part of it...you know you're nervous about it, you're worried about it, you want to make sure you having something that can fill that void...I think once the teacher is an experienced teacher working in an environment for a while, it's a lot easier to understand the way that environment will respond to ambiguity, openness, freedom, all of those things. If you don't know what that is or will be like, you feel more obligated to take care of it. [Byron, Final Interview]

In this series of quotes, Byron discussed the need to understand the capabilities of his audience before shifting to a more student-driven, open-ended style. He expressed an affective, personal component of presenting the same material to a wide variety of audiences and related this to a novice teacher who may not fully understand the culture of their classroom. Byron equated experience with knowing how the audience will react to specific types of situations. Another major reflection from the experience centered on the importance of fostering relationships between participants in a class. He mentioned that “I think that I have learned, although not fully absorbed, the lesson of how important it is to build a sense of community in the beginning” [Byron, Final Interview]. He went on to reflect:

If you can work a class toward an environment where people feel like 'yes, I am prepared to say that and I know that if I say something wrong people won't laugh at me.’ I work a lot on creating that environment with our students here (at the university). They are very resistant to it, especially at first because they've not done that before. They feel like they are extremely smart people and if anything ever happens that reveals that they don't know something it makes them feel really
bad. So, thinking about how you can create an environment where people can be open about not knowing something, treating each other with respect. [Byron, Final Interview]

Byron stated that focusing on building relationships amongst students helps students feel more comfortable about sharing ideas and making mistakes around each other. By doing this, collaborations on projects could run more smoothly and ideas could flow more freely amongst participants. He also discussed how the experience helped him gain more of an understanding of how science is taught in the structure of high school, mentioning:

_I could imagine going into a school thinking I've got 45 minutes, I can do this exercise with students, and I would have scaled an exercise much too large for the purpose. So, I learned something, I think, about how you might... generate materials and activities for the real nature of a high school environment that I didn't know. It's kind of a tiny reality check._ [Byron, Final Interview]

Byron admitted to having a limited view of the constraints in the high school environment, which would shift the structure of the lessons that he presented at the workshop. He then brainstormed how he could overcome some of the structural issues to make sure students could see the bigger picture, saying:

_for example, power laws and plotting those, 2% of high schoolers might get anything out of that, so it might make sense to think about how to avoid that and work on how to explain scaling in a clearer way. It's not a hard concept. This gets bigger, that gets bigger. That's all scaling laws are about, right? Everyone can understand that in some cases, the way one thing gets bigger when the other is fast and in other cases it's slow and why you might be much more sensible to generate some language around that and discuss how it could be growing fast or growing slowly._ [Byron, Observation 3]

Byron cited focusing on the major concepts and avoiding threads that might only serve a specific population by looking at language structure and how the topic is presented. By doing this, more students could focus on the science behind the theory and have opportunities to go deeper in the application and how it is related to their context.

Conclusions

Byron used his teaching experiences to inform his module, as he was able to draw from multiple iterations of similar topics to create a series of lessons that were engaging for the teachers and informative regarding the collaborations of science subdisciplines. He spent his time creating a welcoming environment in which the teachers could explore an application of a
crosscutting concept and he related to their experiences by telling professional stories, recommending engaging extensions for students, and informing ways in which teachers could fuse the norms and practices of multiple disciplines to create a realistic scientific experience. In terms of teaching practice, Byron modeled how to cater lessons to the needs and contexts of the teachers by choosing the activity each week based on previous experiences with the teachers. He also participated actively in brainstorming structures that could help students with the complicated parts of his lesson by asking the teachers for insight to help improve his practice and better relate the material to participants. It was through this collaborative process that small changes to his lesson were made—a participant defined a problem and the cohort discussed potential solutions based on previous experiences. Since he created entire courses based on these lessons and modified them based on years of experience, Byron understandably focused less on curriculum, and more on building relationships with the teachers in order to inform the progression of his course. Through reflecting on these interactions, he was able to draw on multiple experiences to make a lesson that was relevant for the teachers.

3.8.5 Descriptive Cases of Faculty Participants: Eve

Background

Eve is an assistant professor in the College of Engineering who studies design processes and strategies that support successful design outcomes. Her department is diverse in faculty research areas, which provides her opportunities to incorporate interdisciplinary perspectives in her studies. She teaches engineering design courses that incorporate human-oriented design approaches, pushing engineering students to think more broadly than the functional aspects of the artifacts they are designing. In her courses, students are asked to engage with stakeholders to inform the design problem, the development of engineering requirements and specifications, and potential solutions. Eve is also experienced in conducting workshops for secondary and postsecondary instructors and is deeply passionate about processes of teaching and learning.

Engineering can be viewed as a field where projects are designed with specific variables in mind to make a product that is functional, practical, and useful. Since designing functional products requires technical expertise, many classes focus on mathematical concepts and the application of these concepts to build a concrete prototype. Eve defines engineering design as the “application of technology to create an artifact that fits within the culture or context” [Eve,
Member Check. Using this definition to inform her teaching, she says that “my undergrad students have spent all their time with the technical aspects and it's my job to say, ‘Engineering's actually bigger than this. You can't just design technical things in a box, you have to recognize the larger picture’” [Eve, Final Interview]. This includes thinking about the culture and context for whom the project is meant and involving stakeholders in the design process to make a product that will be most useful for the intended population. This process is called human-centered design, which focuses on meeting people’s needs. Eve states:

> It (human-centered design) involves building a deep empathy so you understand where people are coming from. With the people you're designing for, you generate a lot of ideas, you build a lot of prototypes, and you share those pieces... because they're the people who are going to ultimately determine if your design is successful, and then that launches into the world. So human-centered design really sits on this interface between optimizing how things work, optimizing form and function, and optimizing how people think and behave and act in a context. [Eve, Observation 1]

This part of engineering design is often overlooked, which results in well-engineered products being brought into the field and remaining virtually unused because cultural factors were not a consideration during the design process. Eve strives to provide examples and give students chances to critique, problem-solve, and revise designs to gain a lens for considering social variables when completing projects in their future work.

Planning

In general, secondary teachers have a limited understanding of the engineering design process and the nature of being an engineer. This is because engineering coursework is generally a part of their training. Considering this, Eve wanted to design an experience that gave teachers an overview of the engineering design process by capturing both the technical and social components of the field. She mentioned that “engineering design isn't just about optimizing science principles. It's not only about optimizing contextual principles either. Instead, it's trying to figure out how you can balance both” [Eve, Observation 1]. To do this, she combined an engineering design lab that was represented in the NGSS, designing a solar oven, with a lesson she teaches where students develop interviews to learn about everyday experiences of stakeholders to inform variables that needed to be considered in the product. To prepare for the course, Eve and the specialist met once every two months throughout the prior semester, and
then several times in the semester leading up to when lessons were conducted. According to the specialist, “The early meetings were focused on identifying the lesson topics, and the winter meetings were focused on sequencing the lessons and addressing what would be taught” [Specialist Interview]. Eve invited people who were knowledgeable about the application of the product to the course in order to participate as interview subjects for the teachers. Using the interview data, teachers would then be able to analyze the results in order to make their product more accommodating for the interviewed subjects. This mimicked the design process that engineers use when applying human-centered design principles and offered a structure that teachers could use to build lessons incorporating engineering design into their curriculum.

*Instruction*

Eve began the course by leading a discussion describing the design and technical aspects of engineering, asking the teachers about their background experiences and how they saw the two aspects applied in both a professional and instructional setting. She then walked through the goals for the product, outlined the contextual factors that they should consider, and allowed time for brainstorming and designing an initial prototype. As the discussions gained momentum, Eve interrupted the class to set the stage for the rest of the lesson by mentioning:

> We’re asking questions, defining the problem, thinking about what solutions might be, optimizing those through builds and tests, right? And you iterate within that cycle. What these processes don't represent is where the contextual factors interface with defining the problem, with developing solutions, with prototyping and getting feedback. So, we want to talk about a model today that thinks about environment, that thinks about people, that thinks about their priorities, their experiences in everyday life. [Eve, Observation 1]

This transitioned the class to an introduction to human-centered design and the significance of including stakeholders who use the products into the conversation.

The structure of the classroom instruction followed a similar pattern to Eve’s approach when teaching engineering students. With each important aspect of the design process, Eve created a space for participants to discuss where they have seen the concept before and also provided examples and cases for how the concept has been used (for better or worse) in the engineering professional world. In introducing human-centered design, Eve mentioned:

> This is a report from a study where they were looking at bio sand filters that were developed for this particular valley in Haiti. The researchers went back and looked at the success of these bio sand filters, which were essentially developed
and given to these communities as an optimized technical design. But, in their site visits, 47% of these beautifully optimized technical designs weren't being used anymore…the bottom line that the researchers discovered was that they weren't incorporated into the culture—the technologies, the education materials, the maintenance, the operation—because they didn't take those features into account, the bio sand filters were just sort of pushed aside and the community operated as it normally did. Perfectly optimized system technically, but without contextual optimization it failed. [Eve, Observation 1]

Using these cases allowed the teachers to see how the terms were carried out in the real world and to ground the objective of the project in the context of the term. In this particular instance, she followed up the story by telling the teachers:

To start thinking about some of the contextual considerations that we have today. You're going to be designers of some kind of solar cooking device for campers. That's going to be our user group. I want you to think about how we might discover, or how we might define how the solar oven is to be used, where it's going to be used, when it'll be used, who's going to use it, how much space it might take up. So, I want you take that all in. [Eve, Observation 1]

The example shed light on how context relates to their overall project. Eve then allowed the participants to discuss about how the case informs their design by saying, “I want you to talk at your table… What are some other questions about the context of this solar cooking device that you're going to design, might you have?” [Eve, Observation 1]. While the teachers were discussing, she walked around the room and listened to each group, extracting patterns to inform how she should move the lesson forward. The class then shared their thoughts, while Eve offered input that detailed the specific variables engineers consider on a consistent basis during the design process. In this particular example, after the teachers discussed their thoughts as a class, she stated:

These are all the kinds of things that we're going to try to learn more about when we talk to the campers today. We're going use design ethnography methods. So, design ethnography is a collection of research to tools to help us learn about users and contexts. . . Essentially, the idea is that this collection of methods is aimed at understanding experiences of everyday life of the design stakeholders. So, in our context, the design stakeholders are campers who need to cook with a solar oven. There are a lot of design ethnography data collection methods: You can observe people as they engage in these kinds of experiences, focus group surveys, use ability test interviews. [Eve, Observation 1]
This structure allowed the teachers to see examples to ground their project contexts, discuss and share their ideas within and amongst groups, and seamlessly introduce a new consideration of the project (ethnographic methods) in order to engage teachers in the design process. This pattern of events happened consistently throughout the duration of the course, modeling a structured learning environment for the teachers that resembled closely how Eve would engage her engineering students.

After introducing the project, context, and the concept of ethnographic methods to the teachers, Eve told the teachers that they were going to conduct interviews with invited guests during the course in order to learn the concerns of stakeholders regarding their solar oven. She then talked about the trajectory of a good interview to solicit useful information from the interviewee’s stories. Eve provided example questions for participants to critique, offering insight on how to construct more open-ended questions, listen for opportunities for probing questions, and rephrase vague inferences by the interviewee to make the statement more useful and specific for the purpose of their project. In the final part of the training process, she used case studies to help the teachers identify bias and offered suggestions on how to avoid interviewer projections of stakeholder’s comments. Time was given for groups to collaborate and construct interviews, and then the teachers were able to conduct their interviews with actual interviewees.

Eve then discussed how to analyze the results of the interviews that the teachers conducted. Reminding the participants that the goal was to design a product that considered stakeholders’ cultural practices and histories, she gave the teachers a few minutes to look for patterns in the data and then reorganized their groups in a heterogeneous fashion to generate a rich discussion on similarities and differences between design groups. Using examples and collaborative discussion points, Eve introduced how to turn patterns into design requirements, and then design requirements into technical specifications that could be measured quantitatively. After teachers discussed what measurements could be shifted to better suit the stakeholders’ needs, Eve had the original groups reconvene in order to come to a consensus on how these considerations should be utilized in order to shift their initial design. Design tools that engineers use to brainstorm considerations were provided, and the teachers were prompted to try them out to enhance their design. Once completed, groups shared their discussion points with the entire class and then collaboratively brainstormed tradeoffs of the different variables in consideration.
In doing this, Eve showed that every variable had both positives and negatives, and every slight change that is made in a design needs to go through this consideration process before a product goes to market. The course ended with discussion on resources that teachers can use to incorporate a human-centered design process within existing engineering lessons.

**Reflection**

Much of the reflection process focused on helping the teachers acquire a more realistic view of the engineering design process. Many of the teachers did not have any prior experience with human-centered design and the process of soliciting information from stakeholders to design a product, and the lesson provided a means to learn from an actual engineer about the importance of considering the broader impacts of their field. This is captured in the following interaction, in which a teacher voices how Eve’s lesson brought to light the societal impact inherent in engineering:

**Teacher:** I just wasn't used to having these real people come into the classroom and talk about their concerns for the product. It makes it much more real, and you're integrating with society, and that is not usually necessarily the roles of engineers or scientists, and students wouldn't see themselves in that lens, because it makes this whole process not necessarily about a project I'm doing for class, but you're seeing the societal value for it. Some might not see it just as a classroom project, so it engages them more on a societal level.

**Eve:** I think design for engineers is that place where they can translate the technical stuff that they spend most of their curriculum on into how they can impact the world. There's been a good body of research about the power of design in terms of how you can change the world, how can you change social situations, how can you serve or partner with communities where there are design opportunities that can improve ways of life. [Eve, Observation 2]

This interaction showed that the teachers reflected about using these types of lessons in order to build an engineering identity amongst their students while designing products that help the world. Eve related this to her context, stating that engineering is shifting to accommodate a more holistic approach to design. She reflects:

*For teachers too, I think it zoomed out a little bit on their perspective of what engineering could include so I felt a lot better hearing that than what I expected the response to be. I definitely felt like an imposter as an*
Eve mentioned that, in planning this module, her goal was to model for teachers a design process. Even though she mentioned that her non-stereotypical role as an engineer could be a barrier to overcome regarding the typical assumption of engineers as purely technical workers, she was glad that the lesson served to expand the participants’ view of the range of possible careers within engineering. During the discussion in the course, one of the teachers thought aloud about the implications of this lesson in her classroom:

Teacher:  
*That might be one of the first times in this program, in a science class, where I'm seeing something that was not normally taught in science. I thought that was cool, because as a teacher, I always want to find ways to engage all my students, even those who might not have a natural affinity for science, but seeing the interview process and seeing what kind of things could be done there seems to help them to feel like they contributed as well in designing interview questions, or conducting interviews, thinking through those things and storytelling the narrative, and stuff. That was just really an interesting idea.*

Eve:  
*That makes me think one of the things that I think engineers really like about the structure of the interview process is that it has a structure. A lot of times, I feel like when we're in this STEM space, we think that the non-STEM things are just mushy... they don't have rigor. When you represent—actually look at those technical details that are associated with structuring the interview protocol—people are like, "Oh!" It's not just you sit down and you say, "What do you want your design to be?" Right? There's actually rigor that can make or break design success, and that has a big impact on engineers when they think about it that way. [Eve, Observation 2]*

In this interaction, the teacher mentioned how the interviews in the design process could be used to engage students who might not traditionally be as excited about science. In response, Eve talked about how the design interviews added a social aspect to the engineering lesson without diluting rigor, and that oftentimes this helps engineering students see the importance of including contextual principles when considering design. Comparing this to the final interview, Eve mentioned:

*I was surprised that they liked it honestly. I was so nervous that they were going to say, "That's not really engineering," but I was surprised that the teacher said, "This would be good for the people who aren't normally interested or motivated to*
do this kind of stuff." It felt like it came back to me to the reasons that I do what I do at the undergrad level where it helps students recognize the bigger picture of engineering. And they (the teachers) were sort of saying the same thing, people who would have checked out at the traditional lesson, they thought they might be more engaged in some of these other interviewing pieces or creativity pieces. That was definitely surprising, I expected the feedback to be, "This isn't engineering. Why'd you bring her in here?" [Eve, Final Interview]

The quote above demonstrates that she was affirmed by the accessibility of her lesson in that teachers recognized how human-centered design could be incorporated to engage students who are not as interested in science. This account challenged her initial expectation that their exposure to engineering would be more aligned with traditional technical engineering. Through conducting this activity, Eve showed that designing lessons where engineers learn about non-technical skills afforded opportunities for inclusion of students who might be more interested in subjects other than science. On a broader scale, this type of activity offers greater insight into the authentic practice of engineers that includes a social component, which is rarely discussed in secondary settings. Using this type of activity exposed students to the type of work that engineers actually perform on a daily basis.

Eve came to the module thinking deeply about her teaching practice. Eve revealed this well-thought-out structure for how she teaches during the discussions with the teachers. In general, when new tools were introduced that can enhance the classroom, she made space for teachers to experience the tool before applying it to an engineering problem. A discussion about this from the module is included below:

Teacher: I really like the [idea generation tool], but I'm wondering what the first lesson would look like where you brought those in?

Eve: Yeah. I can speak to that a little bit. The reason I kind of side-barred it tonight is because often I talk about idea generation separate from talking about human-centered design. If, I talked about the design process holistically, I go through each phase and talk about best practices, and so, I have a unit where I talk about idea generation. All those different idea generation tools, we talk about how to use, and we practice in different product design contexts. The first lesson is really let's talk about fixing through a limited idea generation space versus broader exploration of ideas. Then, we'll use different tools and practice that. By the time we do this lesson, we already know idea generation tools. When, we develop the requirements, we develop the specifications, when we come to generating ideas, we're not just looking at a blank piece of paper, because we know it's a struggling
point. Instead, we're leveraging the idea generation tools that we've already practiced. [Eve, Observation 2]

Here, Eve reflected on how she built her course to address issues that her students commonly face. She also showed how she considered specific tools and allowed ample time in class for students to overcome struggles that they may have with the tools. Reflecting on how the experience shifted her pedagogical considerations, Eve said:

*The gap that I'm identifying when I'm presenting to your crowd was different than the gap that I'm traditionally used to presenting, so it made me think about just those audience differences and how it totally changes the frame, and the frame became this technical versus ... Or physical versus contextual principles which I think was not an entry that I usually consider.* [Eve, Final Interview]

Here, she emphasized that the contextual differences between high school teachers and undergraduate engineering students shifted her thinking about how she should structure the lesson. In planning the lesson, she assumed that her undergraduate students had plenty of experience with technical engineering and that teachers would need to spend time learning about the processes of engineering. Regarding the teachers, she mentioned that “they're not starting from the place where you're building and pushing on expanding their conception, and so it felt like a different approach than my norm in terms of how I think about engineering my design lessons in engineering” [Eve, Final Interview]. Because of this, she sought out the help of the specialist where they discussed “how participants might translate the ideas in the lesson back to their own teaching and dynamic interplay between content and process in learning engineering” [Specialist Interview]. She reflected on the process by saying:

*If the specialist and I hadn't had those meetings I wouldn't have...framed it in the appropriate way. I really think, for that presentation, was this language that evolved about physical optimization or physical principles versus the contextual principles, and I really think that...I will carry framing with me beyond the course.* [Eve, Final Interview]

Eve mentioned specifically that interactions with the education community helped her think about the language that she uses and how that relates to the context of her audience. When asked to explain more about how context was considered, she mentioned that:

*There's just so much literature about the breadth of what engineering can cover, and I think for the most part at the K-12 level engineering and science are sort of presented equivalently. Not that one's better or worse but you can see that if someone has a predisposition about science that they would carry over to*
Eve reflected that the structure of secondary education required extra steps to be added when discussing engineering, primarily to describe some of the background and more technical components of the field before talking about contextual considerations. In this particular case, she discussed how there is not a clear distinction between science and engineering in high school settings, and therefore it is automatically assumed that students who thrive in science settings would therefore function similarly in engineering settings. To get around this, Eve posited that, “Instead of having to say, ‘Engineering connects to these science principles,’ you could say, ‘This is what engineering is, now let's explore some of those pieces. And then you could draw some connections to other topic areas but it's not just science’” [Eve, Final Interview]. By making this consideration, Eve thought the teachers could make the argument that engineering can leverage skills that might not be present in regular science classes, thus providing a more realistic view of the field itself. In response to working with the teachers, Eve stated:

"I actually just sent out an email this morning with our team and our postdoc is starting to get the materials ready for a workshop and she said, "Should I just use what we've used for the undergrad one and just trim it up a little bit?" I was like, "I actually think we're going to need to think about framing a little bit." So immediate deliverable is like, "I've learned some things about what engineering might look like in the middle or high school setting and now we can think about how high school contexts looks different than undergraduate contexts." [Eve, Final Interview]

Conclusions

Eve presented a case of a faculty member who is comfortable with conveying disciplinary knowledge to students, teachers, and preservice teachers. This quality is evident in how she structured the module by taking care to define key terms, allowing space for participants to interact with the terms, asking questions, and applying the terms to their own projects. Throughout the course, she offered insight on how the engineering field works and considered the stakeholders throughout the design process. The content in this module was similar to that which she already teaches, and therefore the curriculum was not adjusted substantially outside of the beginning framing, being intentional about slide placement in the presentation, scaffolding language to be less technical and more accessible for teachers and allowing for subjects to be
interviewed while in the class. Working with a group of teachers helped her gain a perspective on how to adjust framing of this content to the high school audience. She mentioned several times that she could not assume that the teachers came to the course with a background knowledge of technical engineering, and therefore had to accommodate for this gap in several areas. Eve continued thinking about the structural and contextual difficulties that teachers may face when applying her lesson and was able to generate ideas for future use along with the teachers.

3.9 References


Licona, P. R., & Kelly, G. J. (2019). Translanguaging in a middle school science classroom: constructing scientific arguments in English and Spanish. **Cultural Studies of Science Education, 1**-26.


President’s Council of Advisors on Science and Technology. (2012). *Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering and mathematics*. Retrieved from Washington, DC:


Chapter 4
Cultural Relevance in Chemistry Education: Snow Chemistry and the Iñupiaq Community

4.1 Initial Remarks

This chapter describes how a snow chemistry unit, designed in collaboration with Ilisaġvik College in Utqiaġvik, Alaska and University of Michigan, relates to Culturally Relevant Education (CRE). In many classrooms, science content is depicted as acultural, meaning that issues of culture are considered unrelated to material covered in the course. However, anthropological accounts show that science is a product of culture, and that classrooms in the United States privilege the Western science perspective over students’ cultural ways of knowing, leading to a disconnect between the lived experiences of minoritized students and material that is covered in school. This promotes specific ideas of what science looks like and who is involved in the scientific process, excluding the experiences of many non-majority students. CRE promotes four tenets for teaching classroom content while affirming students’ cultural identities through the inclusion of students’ cultural references in academic skills and content, critical reflection on their own lives and society, promotion of navigating cultures that are different from their own, and the critiquing and dismantling of discourses of power within the classroom and society at large.

This chapter summarizes how a unit on snow Chemistry was designed focusing on tenets of CRE. The study includes overview of how the design team incorporated and affirmed Indigenous research methodologies, considered the Iñupiat cultural context of Utqiaġvik, and utilized collaborative design and implementation methods to disrupt the settler-colonial narrative and power dynamics within the design team due to the importance of considering researcher positionality and socio-political history when working with Indigenous populations. The chapter includes a description of the snow chemistry unit and how it relates to the community of Utqiaġvik. Salient student examples of CRE were chosen from classroom video recordings,
written and verbal student artifacts, community-student interactions, and community presentations that was collected over four iterations of the unit.

Throughout the unit, students connected their cultural references to academic skills and concepts through engaging with the community, structured reflection on their community experiences, and relating these activities to a research project studying inorganic ions in the snowpack around Utqiaġvik. To do this, students weave together Traditional Indigenous knowledge, Western science practices, and local knowledge to explore their research project. The unit also contained numerous examples of students relating snow chemistry to community issues like climate change, caribou migration, coastal erosion, and permafrost layers. Students with diverse backgrounds and experiences worked together to generate a shared understanding of the results of their project, sharing their cultural experiences with one another. Students critiquing discourses of power was difficult to demonstrate within the context of the unit.

Prior to this study, discipline-based education research offered examples of relating cultural references to academic skills and content without regard to the other three tenets of CRE. This study provides an example of how all four tenets can be incorporated within a unit. The author also presents a framework for using environmental chemistry to design classroom activities that weave together community resources and scientific content that includes students gathering information and developing a research question about a community problem, collecting and analyzing environmental samples from around their community, and interpreting their results and presenting them back to their community. The author also advocates for collaborative and iterative methods for design and implementation as a counternarrative to the design process that is used within discipline-based education research.

This chapter first appeared as a practice paper in the *Journal of Chemical Education*’s special issue on diversity, equity, inclusion, and justice. The original publication was modified to adhere to Rackham dissertation formatting requirements, though no additional changes were made. Dr. Linda Nicholas-Figueroa, Prof. Kerri Pratt, and Prof. Ginger Shultz assisted with study design and implementation. Dr. Daniel Wall constructed activities to help the research team and students interact in a culturally sensitive manner with the community of Utqiaġvik. Kaare Ray Sikuaq Erickson worked as a logistics coordinator for Ukpeaġvik Iñupiaq Corporation during the project and guided the research team on connecting with the community as it related to the project. Danielle Maxwell assisted with the data collection and analysis. The author
coordinated the collaborative efforts for design and implementation, collected and analyzed data, wrote the manuscript, and finished all remaining work.

**Original Publication and Copyright Information:**

### 4.2 Abstract

U.S. education generally portrays science from the Western perspective. As a result, students from different cultures, also referred to as non-majority students, often struggle to relate material learned in class to their own cultures and lived experiences. Cultural relevance is gaining momentum in broader education reform movements to relate content in the classroom to students’ cultures and worldviews. Even with this momentum, examples of implementing culturally relevant instruction remain sparse in science education, and in chemistry education in particular. This article outlines a collaboration between Iḷisaġvik College, a tribal college in Utqiaġvik, Alaska, and the University of Michigan, in Ann Arbor, Michigan, to learn more about how culture and context influence the design and implementation of culturally relevant curricular materials for introductory chemistry. Throughout the ongoing process, students work with community members, Elders, and scientists to develop an environmental chemistry research project focused on integrating local, cultural, and scientific resources to explore Arctic snow processes. Participating students engaged in a three-part unit, including information gathering from cultural and scientific resources to develop research questions, collecting and analyzing samples from the local area using analytical methods, and interpreting the data and communicating results to the greater community. Here we outline the design considerations used to construct and implement a culturally relevant chemistry unit. We describe activities where students cultivated relationships with the community and identified resources to inform their research design and classroom interactions. We also detail how culturally relevant education relates to the unit and identify areas where we are still growing as we engage in the design process. Finally, this project demonstrates how a student-driven environmental chemistry project
can connect introductory science students to their community while engaging in authentic research practices.

4.3 Introduction

The low of retention of non-majority students from science, technology, engineering, and mathematics (STEM) has sparked concern from national organizations (Chen, 2013; President’s Council of Advisors on Science and Technology; Seymour & Hunter, 2019). In response, chemistry educators have looked at ways to make STEM content relevant to students’ everyday lives (De Jong & Talanquer, 2015; Sjöström & Talanquer, 2014; Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013; Zeidler, 2014). Often, chemistry focuses on scientific methods and content rather than a connection to community and personal relevance (Bell, Lewenstein, Shouse, & Feder, 2009). Although cultural and socially-negotiated processes govern the construction, validation, and communication of scientific knowledge (Bang & Medin, 2010; Ford, 2008; Medin & Bang, 2014), the results of this process are presented as settled facts in the classroom, which discourages individuals from non-majority groups who may have their own perspectives (Brown & Kelly, 2007; Zidny & Eilks, 2018, 2020). Activities containing science material that is relevant to students’ social identities support their sense of belonging and esteem, helping them succeed in the classroom environment (National Academies of Sciences Engineering and Medicine, 2018). Further, education research reveals that curricular resources are a product of cultural value sets (Kanu, 2006; Medin & Bang, 2014) that affect students’ self-perception and success (Barton & Tan, 2010; Brown, 2004, 2006). Generally, there is an absence of instruction in chemistry education that considers, recognizes, and affirms non-majority cultural perspectives. Here we describe an environmental chemistry research unit that engages students’ traditional and local knowledge alongside Western science knowledge to investigate snow chemistry in the Arctic.

4.3.1 Culturally Relevant Education

Culturally Relevant Education (CRE) is a lens to develop curricular materials that strengthen students’ cultural identities while teaching content and scientific practices embedded within a chemistry classroom (Aronson & Laughter, 2016; Gay, 2010; Ladson-Billings, 1995). CRE integrates students’ cultural and community resources (Moll, Amanti, Neff, & Gonzalez,
with science curricula to promote engagement of non-majority students in secondary settings (Aronson & Laughter, 2016). CRE includes four tenets:

1. Developing connections between cultural references and academic skills and concepts. A culturally relevant educator understands the worldviews and cultural assets students bring into the classroom and utilizes these assets to inform development of curricula.

2. Engaging students in critical reflection about their lives and the world around them. A culturally relevant educator constructs activities encouraging students to consider how course material relates to their community and society.

3. Facilitating students’ cultural competence. A culturally relevant educator builds a classroom where students learn about their own and others’ cultures while teaching students how to navigate the structure and culture of the field they represent.

4. Working to identify and dismantle oppressive systems through the critique of discourses of power. A culturally relevant educator discusses the systemic inequities that affect non-majority students, promoting social justice for all members of society.

Non-majority students can struggle to learn scientific content because they often perceive a divide between the content learned in classrooms and the values, practices, and beliefs in their everyday lives (Aikenhead & Elliott, 2010; Aikenhead & Jegede, 1999; Bang & Medin, 2010). In general, STEM education portrays the values and systems of a dominant Western science culture, undermining how non-majority students experience the world (Medin & Bang, 2014; Snively & Corsiglia, 2001). For example, children from the Menominee community, an Indigenous nation based in Wisconsin, are more sensitive to ecological relations in food chain networks than European Americans (Medin & Bang, 2014). Their perspective places more attention to relationships among species and the roles that humans play within the ecosystem. As a result, Menominee students, and those with similar cultural perspectives, relate less to the presentation of food chain networks from biological texts, which limit the species represented and omit humans as contributing members of a food web (Medin & Bang, 2014). Culturally relevant curricular materials would leverage Menominee cultural resources (e.g., Elders, community members, experiences in an ecosystem) to connect content to students’ lived experiences while teaching scientific content.

While examples of cultural relevance are growing in other sciences (Aronson & Laughter, 2016; Bang & Medin, 2010; Barton & Tan, 2010; Medin & Bang, 2014; L. Nicholas-
Figueroa et al., 2015), chemistry education has relatively few. Reports show that modern films (Collins & Appleby, 2018) and food (Goethe & Colina, 2018) connect students’ cultural references and lived experiences to chemistry content in the classroom. Environmental chemistry research experiences also connect chemistry content to place and culture, providing opportunities to engage with science that relate to activities and resources of direct concern to students’ own communities (Zidny & Eilks, 2018, 2020). For example, Scholes et al. (2019) focused on traditional Indigenous practices, such as toxin removal from plant seeds, and connecting them to their associated chemistry content as a way to improve student interest in chemistry. (Scholes, 2019) While these activities connect classroom content to students’ cultural references, further work is needed to engage in all recommended practices of CRE including critical reflection, facilitating cultural competence, and critique of discourses of power to engage students in promoting, utilizing, and reflecting on their cultural knowledge systems.

4.3.2 Cultural Relevance in the Arctic

The Arctic region, known for its rugged landscape, harsh weather, and intense seasons, is currently experiencing even more variable environmental conditions due to global climate change (Overland et al., 2019). Declining sea ice extent and increased permafrost thaw are examples of the added challenges facing the Iñupiat communities in northern Alaska (Overland et al., 2019). Situated at the northernmost point of the United States, Utqiaġvik, Alaska has been home to Iñupiat people for thousands of years (Erickson, 2020; Wohlforth, 2005). Over this time, the Iñupiat culture has built up a deep body of knowledge, also referred to as Indigenous Knowledge, about the Arctic environment, the living animals in the environment, and how humans fit into and relate to others in the Arctic environment (Aikenhead & Elliott, 2010; Ascher, 2002; Eglash, Bennett, O’Donnell, Jennings, & Cintorino, 2006; Erickson, 2020). Education has always been crucial for the Iñupiat to pass on this body of knowledge. Through education, this body of knowledge is extended and deepened by allowing young...
students to personally experience phenomena in the environment while being guided and kept safe by family and community members. Traditional storytelling and Iñupiat dancing are also forms of education in the Iñupiat culture (Barnhardt & Kawagley, 2008; Cajete & Bear, 2000; Erickson, 2020). Seasonal subsistence hunts, sea ice navigation, and food storage are examples of Traditional knowledge that is shifting because of the changing climate, affecting the daily lives and culture of those living in the Alaskan Arctic (Erickson, 2020; Wohlforth, 2005).

Science curriculum taught in American schools generally adheres to a Western perspective, emphasizing compartmentalized knowledge that is decontextualized. This approach to science education conflicts with Indigenous populations’ learning processes using direct experience in the natural world, leading to a divide between traditional knowledge structures and Western science practices taught in classrooms (Barnhardt, 2005). For instance, students whose central concerns about the environment involve questions about safely navigating the sea ice and other aspects of the subsistence cycle may not see value in the standard scientific curriculum. In Utqiaġvik, there is an educational effort to emphasize a holistic knowledge of the changing Arctic—a common ground between knowledge systems that students use while participating in scientific activities (Barnhardt, 2005; Nicholas-Figueroa et al., 2015; Sigman et al., 2019).

A vibrant history of the scientific community partnering with an Indigenous community that possesses extensive knowledge of the local environment makes Utqiaġvik a place where local students can easily access authentic scientific practices while considering the diverse representation of cultures in the classroom (Erickson, 2020). For instance, co-author Nicholas-Figueroa introduced a project with a two-week program on the understanding of the carbon cycle and its impact on climate change. In this program, secondary students engaged with Elders and scientists, where Elders spoke of topics that had direct effects on the local environment and the subsistence community and scientists communicated about the fundamental relationships between the carbon cycle and the local environment (Nicholas-Figueroa, Hare, van Muelken, Duffy, & Middlecamp, 2017). Examples like this demonstrate that environmental chemistry can serve as a tool to bridge the scientific and local communities, allowing students to explore scientific concepts that are important to the community through a lens that draws upon their unique cultural resources to inform their projects.

Engaging students in research practices centered on environmental chemistry that is informed by local and visiting educators, scientists, community scholars, and Elders may
contribute to a curriculum intersecting the norms and practices of Western science and the traditional knowledge systems of Native Alaskans (Barnhardt, 2005; Linda Nicholas-Figueroa, Wall, van Muelken, & Duffy, 2017). Herein, we describe the design and early implementation of a culturally relevant chemistry unit in the introductory science classroom at Ilisaġvik College, a two-year tribal college in Utqiaġvik, AK. While the college strives to serve the community while promoting Iñupiaq values, it is important to note that a large portion of the student population are non-Indigenous with a diverse representation of cultures. Consistent with the approach used at Ilisaġvik College, this unit focuses on snow chemistry and processes relevant to Arctic climate change and the lives and culture of the people of Utqiaġvik. The project involves multiple cohorts of the Utqiaġvik community, including Iñupiat and local students, Elders, and professors at Ilisaġvik College, in addition to scientists and chemistry education researchers to learn about how culture, context, and place inform the development of a culturally relevant chemistry unit. This article outlines the considerations made while developing a culturally relevant chemistry unit, including cultivating interpersonal relationships and identifying resources students use to inform classroom activities. We also describe this unit’s alignment with CRE and identify areas we are still growing while designing curricular materials that place students’ cultures at the forefront. Finally, this project demonstrates how environmental chemistry connects students to their community while engaging in research practices.

4.4 Snow Chemistry Module Design Process

4.4.1 Partnering with the Community

Throughout this process, we sought to co-design products to serve the greater good of the community using methods that affirm Indigenous populations (Defries, 2014; Kovach, 2010; Smith, Tuck, & Yang, 2018; Windchief & San Pedro, 2019). We seek to honor participation by the Utqiaġvik community in mutually beneficial ways, such as constructing spaces where students learn from, communicate, and celebrate their findings with the community while obtaining and incorporating community feedback into the design of the project. We also support the community in promoting the design work to the greater Iñupiaq, science, and education communities. We recognize the importance of honoring relationships built through the project and are grateful for the knowledge that the participants in our education project choose to share.
(Tuck & Yang, 2014). This perspective requires reflection on our positionality to determine how our views influence our process. Positionality recognizes power and privilege differences between the project team and stakeholders along with the historical and contemporary realities in the community (Costanza-Chock, 2020; Esmonde & Booker, 2016; St. Louis & Calabrese Barton, 2002). The project team consistently engages in reflection on specific instances in the classroom and students’ interactions with community members to grow our understanding of power and culture and how they affect students and their families.

The project described in this paper is rooted in early conversations between two of the authors, a scientist who specializes in Arctic research, and a local Inupiat science liaison who worked for Ukpeaġvik Iñupiat Corporation (UIC) Science, an Inupiat owned and operated science logistics business in Utqiaġvik. The early conversations focused on the observation that a bulk of science-Indigenous partnerships in Arctic research typically focused on how local and Indigenous knowledge can contribute to Western science. The authors of this paper began to brainstorm together on how one could potentially reverse the situation and look at how Western science can contribute to local and Indigenous knowledges through direct interactions of students with the community. This entire project is based on this premise. Relationships between project members were built from the initial interaction and include a coauthor, who is a science professor, self-identifying as Black, at Ilisaġvik College with a research background integrating local and Indigenous knowledge in the introductory science classroom. Another coauthor, an anthropology professor at Ilisaġvik College, self-identifying as White, lends knowledge of interactions with community members and socio-politico-historical context as students and the project team partner with the community. The education project team (referred to as “we” and “us” throughout) contains members situated at Ilisaġvik College and the University of Michigan (UM). The Ilisaġvik College team brings knowledge of local and community resources, an understanding of the student populations, experience developing culturally relevant curricular materials, and connections to community members who can visit the classroom. Members of the UM team bring connections to the scientific community, experience integrating environmental chemistry research in the introductory chemistry classroom (May et al., 2018), and conducting education research. Some team members are still learning about the effects of colonization on non-majority peoples’ identities. Due to culture differences between institutions, we rely on relationships and interactions with the local community to guide our design and implementation
of the snow chemistry unit. We also consult with individuals familiar with Iñupiaq culture (e.g., Elders, subsistence hunters) and invite community members into the classroom to inform our project. Through these consultations, we learned about ways to guide students in thinking about their experiments, important community events that affect the flow of the unit (e.g., Whaling captain’s meetings), and meet other people in the community who may be interested in collaborating with us.

4.4.2 Unit Design and Adaptation

To begin the curriculum design process the team met in Utqiagvik in spring 2019 and spent time learning about the community. The team observed the science classroom at Ilisaġvik College, and co-author Nicholas-Figueroa discussed her approach to and beliefs about teaching and her perspectives on incorporating tenets of Iñupiat culture in her classroom. For instance, her students perform an extraction in her chemistry and life sciences classes using coltsfoot, an herb found throughout the region identified as medicinal by the Iñupiat community. The team talked with students about their experiences learning science in Utqiagvik and visited multiple classrooms at the secondary and postsecondary levels to learn about how science is taught in schools. During the visit, the team hosted a public presentation in which we outlined our design plan for the student-driven research project to community members, offering a space to solicit feedback on increasing community involvement in the project. Our team worked with local Iñupiat research logistics providers and outreach coordinators to ensure activities and public presentations correlated smoothly with other local science outreach and community engagement projects.

The experiences from the first team meeting in Utqiagvik framed a collaborative workshop at UM in summer 2019, where the project team discussed ways for students to reflect on their cultural identity while engaging in science practices surrounding snow chemistry. We constructed activities where students identify cultural resources that inform a research project, reflect upon those resources in relationship to content learned in class, and develop a research question aligning with the project's cultural and scientific elements. We discussed ways to leverage community participation throughout the course to connect students directly to community members to inform their projects (Godínez Castellanos et al., 2021). The project team discussed the uses of ion chromatography and accessible titration methods to measure
inorganic ions in snow samples (May et al., 2018). We frequently consulted the notes and recordings of both team visits while initially developing the unit's components and over the next several semesters of implementation. While designing the materials, the project team worked to ensure that the snow chemistry unit was responsive to Iñupiat culture and feasible for the classroom context at Ilisagvik College.

The team is using Design-Based Implementation Research (DBIR) (Penuel & Fishman, 2012), which is well-suited to the culturally-sensitive nature of our project due to its focus on collaborative and iterative engagement to sustain the unit past our involvement in the community. Principally adapting curricular materials for a specific context in collaboration with stakeholders (e.g., community members and students) is an important component of DBIR. A future manuscript will focus on the details of this adaptation; whereas, our purpose here is to focus on tenets of CRE. We implemented three iterations of the snow chemistry unit at Ilisagvik College in Fall 2019 for a first-semester general chemistry course, Winter 2020 for an introductory climate change course, and Fall 2021 for an introductory-level chemistry and society course. Enrollment in the courses included 18 total students, many self-identifying with a range of cultures including Alaska Native (Iñupiat), Filipino, LatinX, and White. The project team collaborated in weekly meetings, discussing general impressions of the course, adaptations to the unit, and logistical constraints. At the end of each semester, the project team reflected on the support structure and classroom interactions throughout the semester to inform the unit’s adaptation for subsequent iterations.

4.4.3 Snow Chemistry Unit

The snow chemistry unit consists of three sections (Figure 4.2). The first section focuses on gathering information about snow and ice from the local community and from Western science to develop a research question. This section includes listening to stories about the changing snow and ice from an Iñupiaq Elder to guide students on prior knowledge produced by community members and scientists before choosing a question to study. The students develop an interview protocol, with guidance from the Ilisagvik College Anthropology professor, and talk with community members to refine what they could study in the project. This is important because interviews in Iñupiat communities have differing norms and practices than what
regularly occurs in education research, and students benefit from guidance on how to respectfully engage in this way. Additionally, this approach intentionally positions students, rather than the instructor or project team, to interact directly with community members to learn about their knowledge systems. While students conduct interviews, they also learn in the classroom about prior snow chemistry research through a Process-Oriented Guided-Inquiry Learning (POGIL) activity (Moog & Spencer, 2008). We recognize that environmental chemistry and POGIL communities use the term ‘model’ differently, so we are defining it as a representation of a scientific phenomenon (National Research Council, 2012) that grounds students’ discussions while participating in the POGIL activity (Moog & Spencer, 2008). Within the POGIL activity, students collaboratively work through questions associated with models based on figures from primary snow chemistry literature to learn about pathways of sea salt addition to the Arctic snowpack (Domine, Sparapani, Ianniello, & Beine, 2004). Throughout this section, students reflect on each activity, how the activities are related, and elements of culture that could inform a research question. The section concludes with students developing research questions to guide the collection and analysis of local snow samples.
The second unit section focuses on student analysis of snow samples collected near Utqiagvik. After developing a research question, the whole class develops a snow sampling experimental design protocol outlining outdoor safety, materials needed, procedures to avoid contamination, and sample storage methods. When possible, the students test their protocols in small groups by conducting a mock snow sampling trial outside of the laboratory and revise their protocols from their experience. Before collecting samples in the field, students present information used to inform their research question and their snow sampling protocol to a science professor who conducts snow chemistry research in Utqiagvik. After receiving feedback, students reflect on the process of interacting with a science professor and their sample collection protocol adaptations. Snow sampling is dependent on local weather conditions and safety considerations, and any snow sampling occurring outside of town requires guidance of local community guides (e.g., polar bear guards) to ensure safety. Students use the Mohr method (Ibanez, Hernandez-Esparaza, Doria-Serrano, Fregoso-Infante, & Singh, 2008) to measure snowmelt chloride concentrations through titration using silver nitrate and a potassium chromate indicator, following previous application in the introductory chemistry classroom for this purpose (May et al., 2018). When snow sampling was not feasible due to COVID-19, a large dataset of Utqiagvik snow inorganic ion concentrations, previously obtained by UM general chemistry students using ion chromatography (May et al., 2018), and maps of sampling sites were made available to the Ilisaġvik College students. The students used these data to answer their research questions, which were adapted as needed based on the data available.

Students interpret and share their results with the community in the third section. Students graph their chloride concentration data in a manner that aligns with their research question, using examples from literature (Domine et al., 2004; Jacobi, Voisin, Jaffrezo, Cozic, & Douglas, 2012; Krnavek et al., 2012) and receiving feedback from the project team to further their computation skills using spreadsheets. Once students construct representations of data (e.g., graphs) and discuss their interpretations, teams of students construct presentations telling the story of their research project. Due to logistical constraints and the COVID-19 pandemic, student presentations occurred virtually through public presentations. The unit concludes with an activity where students reflect on their experiences with the project, what they learned, and changes they would make to guide future students in their projects. For instance, when asking students about how we could structure reflections to encourage deeper responses, they recommended that we
incorporate more verbal reflection to align more with how they interact outside of the classrooms. In response, we switched most of our reflection prompts from a written to a verbal format.

4.5 Findings

This collaboration engaged a range of stakeholders from the community of Utqiaġvik to learn about how culture, context, and place inform the development of a chemistry unit that affirms diverse cultures. In doing this, we explore how aspects of this unit align with the four tenets of CRE outlined in Aronson & Laughter (2016): Connections between Cultural References and Academic Skills and Concepts, Cultural Representation and Critical Reflection, Facilitating Students’ Cultural Competence, and Critique of Discourse of Power. Each section below focuses on a tenet of the framework by describing operationalization of the tenet in the unit's design and implementation, which is illustrated with a specific example. Assigning researcher-generated pseudonyms can be harmful to non-majority populations’ cultural identities (Lahman et al., 2015); therefore, we use general terms (e.g., student 1) with a brief description of the student’s cultural background and experiences that are important to the example. We also use gender neutral pronouns (they/their) to protect the identity of students due to the small number of participants in the course. Each student consented to participate following our IRB protocol.

4.5.1 Connections between Cultural References and Academic Skills and Concepts

Students possess a wide range of cultures, experiences, and resources that contribute to their identities and influence their experiences in academic spaces (Moll et al., 1992). CRE leverages the resources that students bring to inform instruction. As a design principle, we constructed activities where students also identify and explore resources present in their community and use those resources to inform scientific practices. For instance, students learn about snow from an Elder visit to the classroom, conduct community member interviews and explore artifacts at the Iñupiat Heritage Center through an information-gathering assignment, and learn about inorganic ions in the snowpack through the snow chemistry POGIL. Students use these resources to construct research questions and design sample collection strategies that explore chloride content of the local snowpack. Students employ a diversity of resources based in traditional, scientific, and local knowledges (Figure 4.3). For the purposes of distinguishing
cultural references from other resources, we label the resources as traditional, scientific, and local knowledges (Figure 4.3). We defined traditional resources as knowledge that originated from Iñupiat knowledge systems (e.g., Elder visit to the classroom, Iñupiat Heritage Center, community member interview, and knowledge that the students had already learned in their lives). Scientific resources are knowledge that students use from a Western science perspective (e.g., snow chemistry POGIL). Local resources are knowledge that comes from the community that is neither Iñupiat nor from the scientific community (e.g., local residents). We found resources around Utqiagvik that informed students’ projects, identified in Figure 4.3, from student artifacts and classroom discussions. We recognize that splitting up knowledge sources is a Western Science-centered depiction of knowledge that may not translate how Indigenous communities think about knowledge (Barnhardt, 2005; Erickson, 2020) and we recognize that the three knowledge categories are not mutually exclusive. However, to design for CRE, we need to consider how these knowledges are woven together as students often viewed these resources as blended. For instance, some Iñupiaq students consider Iñupiat knowledge of whaling patterns as scientific knowledge passed down in experiential learning settings (e.g., while whaling). Often, students did not distinguish between scientific and traditional knowledge systems and
could recognize the intertwined nature of knowledge sources, represented as a braid in Figure 4.2.

One example of this tenet of CRE comes from student 1, who identifies as Iñupiaq and who is considered to be non-traditional in most university contexts. During the Elder visit in the classroom, students asked questions about potable water sources while hunting or whaling. After the visit, student 1 reflected about the discussion of melting different layers of snow for drinking water and noted that the Elder’s comments reminded them of seasonal caribou migration patterns around Utqiaġvik and their experiences hunting—caribou instinctively migrate towards sea ice due to the mineral content in the snow. They explored this knowledge, utilizing yearly caribou migration patterns from the Bureau of Land Management and considering the origins of sea salt in the snowpack from the snow chemistry POGIL to consider the intersection of these data to investigate areas where caribou migrate around Utqiaġvik. Their research question focused on differences in chloride concentration based on proximity to caribou herds and snow depth.

4.5.2 Cultural Representation and Critical Reflection

Culturally relevant educators engage students in critical reflection by developing curricula and activities that support students’ understanding of the cultures represented in a classroom. Educators engage in critical reflection by constructing activities that dialogue about culture, leading students to develop an understanding of and value towards multiple cultures. Within our snow chemistry unit, students engage in critical reflection through the information gathering assignment by reflecting on information learned from community resources, community member interviews, and summarizing their knowledge sources in classroom discussion. After presenting their research questions and snow sampling protocols for the chat with the science professor activity, students compared the science professor's cultural background and scientific knowledge to their identities and scientific knowledge. At the end of the snow chemistry unit, students reflect on their classroom experiences through their community presentations and a final class reflection. Initially, we developed many of the reflective prompts as formal, written exercises. To align the classroom and reflective prompts with the Iñupiat’s history of verbal storytelling, we shifted our initial reflective prompts to informal, oral reflective class sessions.
During the *community presentation*, students presented their research design and findings to community members and project team. One high school student, who enrolled in the class as a part of a dual enrollment program, engaged in *critical reflection* with another student, who was in their first semester at Iḷisaġvik College, at the end of their presentation. Student 2 identifies as Iñupiaq, and student 3 identifies as Filipino. Student 2 reflected that the unit challenged them to “think outside of the box,” requiring them to use a variety of community and scientific resources in their project. Specifically, they discussed the importance of incorporating community members' voices while considering their research questions and sampling protocol. Student 2 also discussed Elders’ direct knowledge about the changing Arctic since they experienced climate change throughout their lives. Student 2 recognized that they would become an Elder and would need to inform others about their experiences with climate change in Utqiaġvik to help their community. Student 3 expanded upon student 2’s reflection, describing how they used resources outside of the internet to complete the project. Student 3 described how their high school science projects make them use only online resources to find specific answers. In contrast, this project encouraged Student 3 to seek community and scientific resources to investigate open-ended issues. By developing research questions and snow sampling protocols based on the knowledge of several sources, student 3 recognized the influence of multiple worldviews while designing their research project.

4.5.3 *Facilitating Students’ Cultural Competence*

CRE fosters students’ *cultural competence* by creating space where students learn about their own and others’ cultures, emphasizing the importance of cultural diversity and validating students’ cultural identities. Educators construct reflexive spaces where students learn about others’ lived experiences and perspectives, using this information to reflect on their own identities (Adams, 2006). Activities building cultural competence allow students to take pride in their culture while learning about other cultures in the process. Students engage with cultural competence in the snow chemistry unit in several instances. Community members discuss their experiences with snow and ice during the *information gathering assignment*, and students compare and contrast these experiences with their own. Several interviews focused on shifting cultural practices due to changing sea ice extent, providing students with knowledge about Iñupiat culture and environmental changes occurring in their community (e.g., melting
permafrost). Students also summarize their knowledge sources in the *information gathering assignment*, discussing their findings from literature sources and interviews with community members. After the *chat with the science professor* activity, students compare and contrast the professor’s cultural background and scientific knowledge to their own. These activities teach students to navigate multiple world views as they construct their research questions and snow sampling protocols.

A partnership between student 4, who identifies as a White and non-traditional student, and student 5, who identifies as an Iñupiaq student, demonstrated the *facilitation of cultural competence*. Prior to the course, student 4 had limited knowledge about Iñupiat cultural practices and could not describe their own culture. Student 5 viewed classroom science as an embodiment of White culture, assuming initially that student 4’s views aligned with this perspective. Both students explored their perceptions of the other students’ culture from the context of snow chemistry during the *chat with the science professor* activity when they described the knowledges that informed their research question. For instance, student 5 told stories about their parents’ and grandparents’ experiences living in Northern Alaska, and student 4 reflected on these examples throughout their research project. Student 4 also discussed that student 5’s experiences in Northern Alaska provided a perspective where student 5 and the science professor contained different types of expertise on the subject. For example, while the science professor could describe complex phenomenon about a particular part of the nature of snow and ice, student 5 could discuss the different types of snow and their relationship to lived experiences affecting their life (e.g., finding water sources). Student 4 described that they did not align with the scientist, stating that “scientists see the world as black and white, and [they approach] the world more artistically.” Student 5 never considered this perspective before and asked questions about how student 4’s and the scientist’s views differed. Both students noticed that their cultural perspectives could construct a more nuanced research question that involved a complex phenomenon and its cultural implications. By the end, both students could point out interactions where they learned about differences in perspectives of science and the environment that were a part of Iñupiat and White culture.
4.5.4 Critique of Discourse of Power

It is important to recognize the effects of power and privilege when discussing issues that involve the intersection of cultural, educational, and community values (Esmonde & Booker, 2016). Nieto and McDonough (2011, p. 371) mention: “focusing on diversity and multiculturalism without attending to issues of power, racism, and whiteness only serves to reproduce systemic inequities under the guise of multicultural education.” CRE focuses on building an environment where students learn about and critique power structures so that they can navigate, identify, and dismantle inequitable structures affecting their daily lives, communities, and professional outcomes. Designing structures promoting this type of discourse while aligning with the objectives of the snow chemistry unit proved challenging. Students could reflect on experiences and perspectives regarding discourses of power following the chat with the science professor activity. To solicit feedback from the professor, students present their research question, sampling plan, and knowledge sources that informed their experimental design. In the reflection activity, students had a choice of prompts to which they could respond. For one prompt, they could discuss their feelings about the feedback process, changes to their research question and sampling protocol, and places where they are resistant to change because of cultural factors. This activity aimed to capture tension between cultural knowledge systems and the Western scientific perspective, offering a space where students could discuss the power dynamic of expertise and how it affected their actions.

Most students chose to answer other reflective questions that did not relate to critiquing discourses of power. The few students that answered this question responded only in a positive manner. For instance, students reflected that they revised their initial research question based on feedback because “[the professor] knows much more about snow” and thought suggestions would provide a better experimental outcome. Other students commented that they based their research question revisions on interactions with UM team members or the snow chemistry POGIL activity. While we recognize the team members and the snow chemistry POGIL activity are valid scientific resources that students use to inform experimental design, students were hesitant to challenge this scientific perspective. From a cultural lens, it is important to note that shared Iñupiq values students learn within families and the education system could affect how they engage with the prompt (Alaska Native Knowledge Network, 2006). For instance, Respect
for Elders and Avoidance of Conflict are deeply engrained values for students, so they could be reluctant to insert their ideas if they viewed the science professor as their Elder and wanted to avoid conflict in this situation. Based on this, we are exploring ways to better engage students in critiquing the discourse of power through the unit.

4.6 Conclusions

4.6.1 Designing for Cultural Relevance

CRE recognizes and utilizes students’ cultural resources to engage in course materials. In our case, this involves engaging with local, traditional, and scientific resources that students use to develop research questions around snow chemistry. The project team utilizes a three-part cycle (Figure 4.2) to engage in context-based authentic environmental chemistry research in the classroom: (1) students explore cultural resources about snow and ice through information gathering activities, using this information to develop research questions that are relevant to their culture and daily lives; (2) students collect and analyze data using analytical techniques accessible in the Ilisagvik College science classroom; (3) students interpret and communicate their results back to the community so that they could celebrate their work and solicit feedback from people who are knowledgeable and interested in the subject. This cycle is iterative, meaning that previous research questions, results, and community feedback inform how future students design their research question and experiment. We represent local, traditional, and scientific worldviews as a braid wrapping around the cycle, informing each step and connecting students to parts of their identity they explore and celebrate. Each aspect of the unit is student-driven, where the instructor facilitates students’ interactions with the community and teaches the titration method used to analyze the snow samples. While this unit relates to our particular snow chemistry project in the Alaskan Arctic, the general components have the potential to transfer to other classrooms serving students who identify with non-majority cultures to connect cultural resources and environmental chemistry research in the introductory science classroom.

4.6.2 Flexibility as a Design Principle

Throughout the implementation process, the project team considered contextual characteristics of the community and location that affected the outcome of the unit between
iterations. During the project, we regularly discuss cultural differences between institutions. For instance, many community participants who volunteered with the students held important community positions that took precedence over course events. Because community participation with the students is critical for the project, we often shifted to accommodate for community members’ responsibilities. To do this, we reframed selected activities based on who was available and what was most advantageous for the context, making the activities modular in nature. As a result, if an Elder became unavailable, we had other cultural activities to move the students forward in their project. The community’s culture is characteristically flexible, and the Ilisaġvik College professor regularly accommodates the needs of students due to cultural events and weather conditions. Examples of these accommodations include professors shifting syllabi to ensure full content coverage and using digital communication platforms (e.g., Zoom) to accommodate remote learning. As a team, we reflected on the norms of our collaboration (Engle, 2008) and considered potential shifts as we adapted the materials to increase flexibility. Re-conceptualizing the activities to be modular in nature also helped to design the unit with flexibility in mind. While these specific cultural characteristics may be unique to Utqiagvik, the focus on flexibility could be transferred to other contexts and is a critical aspect of the DBIR framework. We will focus on our process of adaptation in another publication relating to this work.

4.6.3 Focus on Connecting with the Community

It is important to promote and honor the community engaged throughout the project. We found it critical to engage with community members early in the design process, listen to their concerns and suggestions, and respond with concrete design adaptations. Often, curriculum design and research occur separately from the community, leading to curricula that does not align with community values (Bang, Faber, Gurneau, Marin, & Soto, 2016) and research that captures a limited cultural perspective (Tuck & Yang, 2014). It was helpful to incorporate many perspectives from esteemed community members for two reasons. First, it expanded our views of expertise beyond the project team to include a range of individuals engaging in a broad scope of activities related to snow, keeping us from inadvertently promoting the settler-colonial narrative rampant in outreach and research activities with Indigenous populations (Smith et al., 2018; Tuck & Yang, 2014). Second, it distributed responsibility in relating to students to include
people involved in the students’ lives outside of academic environments. This approach relates more closely to how many people learn in Utqiaġvik through experience and intergenerational guidance (Barnhardt & Kawagley, 2008; Cajete & Bear, 2000). These community interactions served as concrete and experiential ways students could reflect on cultural differences and the implications of their work.

Finally, building trust and rapport with a community takes time and commitment by the project team—the project's foundation was built after years of interaction between several of the project team members and with the Utqiaġvik community. To engage in the discussion of cultural resources, it is necessary for the project team to adopt a position of extreme humility when interacting with the community, as we are honored to collaborate within cultural knowledge systems that deviate significantly from our own. This stance allows us to cultivate sustained relationships with the community informing how we can design culturally relevant activities for students in our classrooms.

4.7 Acknowledgments

We would like to acknowledge the community of Utqiaġvik for their warm hospitality and willingness to share with us their culture and community resources. The UM team thanks Ilisaġvik College, and the many instructors who welcomed the UM team into their classroom and homes, to show us what makes Utqiaġvik a unique place to teach, learn, and live. We recognize the work done by the Ukpeaġvik Iñupiat Corporation for supporting the project team while working with the people of Utqiaġvik. We appreciate the hard work and dedication that Ilisaġvik College students put in while participating in the unit and the Utqiaġvik community members who volunteered to guide the students in their projects. We thank the National Science Foundation for funding the project (Award Number: 1821884). We acknowledge J.J. Mayers and Ina Zaimi (UM) for their contributions to the initial design and implementation of the UM workshop. Finally, we thank Leah Bricker, Vilma Mesa, Jared Ten Brink, Anne Gere, and our advisory board for conversations that refined our understanding of the history of Indigenous peoples in North America, power and privilege in the classroom, and our positionality and its effects on the research process.
4.8 References


De Jong, O., & Talanquer, V. (2015). Why is it relevant to learn the big ideas in chemistry at school? In Relevant Chemistry Education (pp. 11-31): Brill Sense.


182

President’s Council of Advisors on Science and Technology. (2012). *Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering and mathematics.* Retrieved from Washington, DC:


Chapter 5
Using Conjecture Mapping to Track the Collaborative Design and Implementation of a Culturally Relevant Chemistry Unit

5.1 Initial Remarks

This chapter describes the design and implementation process for a snow chemistry unit designed through a collaboration between Ilisaġvik College in Utqiaġvik, Alaska, and the University of Michigan. The unit was constructed around the tenets of CRE (as outlined in Chapter 4), considering how culture, context, and place inspired various aspects of the design. In particular, this study details how the design team collaborated to construct a unit that affirms students’ cultural perspectives alongside Western science. The unit was implemented at Ilisaġvik College over four iterations with a diverse representation of students in both age and culture. Data collected from classroom observations, collaboration meeting observations, written and verbal student reflections, student artifacts produced from the course, and a capstone community presentation informed adaptations to the unit that ensured outcomes aligned more closely with the tenets of CRE.

The design process was tracked and qualitatively analyzed using conjecture mapping, a tool that systematically identifies a design conjecture, proposed outcomes for students, activities intended to explore the conjecture with relation to the outcomes, and processes that mediate whether the activities achieved the intended outcomes. An initial conjecture map was constructed at the time of the initial design. This initial conjecture map was revisited throughout the design process to structure reflection on how students interacted with designed activities in relation to the intended outcomes. The initial conjecture map was also used in data analysis to track adaptations made to the unit throughout the implementation process. The analysis provided insight and reasoning behind design adaptations to the unit, producing conjecture maps depicting how the four tenets of CRE evolved throughout implementation. This chapter analyzes
conjecture maps related to how the unit connected cultural references to academic skills and concepts (Tenet 1).

Results show that conjecture maps could be used to establish a coherent design narrative throughout multiple iterations. Conjecture maps allowed the design team to reflect on student data and make adaptations to specific design elements that promoted the intended outcomes. For example, the structure of activities was shifted to be more modular in response to the uncertain timing of community members visiting the classroom so that the professor could choose between ways of community engagement based on available resources. The result contributed to students focusing more on Traditional knowledge due to the inclusion of more community resources in the classroom. Instructionally, student reflection activities were shifted from a written to a verbal format after student feedback on the quality of responses with written prompts from the initial design. This adaptation resulted in more detailed student responses to reflective questions, allowing the team to follow up and learn more about the students’ lived experiences outside the classroom. The design team also made interactional adaptations centering on interactions with participants throughout the study, establishing a discourse norm that allowed students to make a more salient connection between Traditional knowledge and Western science during Iterations 2 and 3.

Insights suggest that while conjecture mapping can be used to structure and track intentional adaptations, it has varied implications for the design process. Design teams can use conjecture mapping to structure reflection on expectations as it relates to the intended outcomes. This can unearth hidden tension between individual design team members' backgrounds, experiences, and goals and allow creative responses to the different perspectives. However, as a design progresses through iterations, conjecture maps become exceedingly complex, potentially making them inaccessible to those unfamiliar with the process. This limits who engages with the conjecture map to inspire adaptation, leading to an unintended barrier to the goal of including multiple stakeholders in the design process.

This chapter is being prepared as a publication for submission to an interdisciplinary learning sciences research journal. Dr. Linda Nicholas-Figueroa, Prof. Kerri Pratt, and Prof. Ginger Shultz assisted with the study design and implementation and provided feedback while the manuscript was drafted. Kaare Ray Sikuaq Erickson worked as a logistics coordinator for Ukpeaġvik Iñupiaq Corporation during the project and guided the research team on connecting
with the community as it related to the project. He also wrote a part of the manuscript. Danielle Maxwell assisted with the data collection, analysis, and drafts of the manuscript. The author coordinated the collaborative efforts for design and implementation, collected and analyzed data, wrote the manuscript, and finished all remaining work.

5.2 Abstract

Collaborative curriculum design is complex, especially when the cultures and identities of the designers differ from the communities where the design is implemented. This complexity makes it difficult for collaborators to determine how to innovate in a way that is effective for a specific context. Conjecture mapping is a promising approach because it tracks the design process, offers a framework that captures design elements, uses data collected by the collaboration team, and captures adaptations made between iterations in a design project. This project details a collaboration to explore how culture and context influenced the design and implementation of culturally relevant curricular materials for introductory science courses at Ilisaġvik College in Utqiagvik, Alaska. For this process, we worked with community members, Elders, research scientists, college professors, and students to develop a classroom-based research project that integrates local, traditional, and scientific resources to explore Arctic snow processes. Specifically, this paper examines our use of conjecture mapping to track how students engaged in the tenets of CRE within the snow chemistry unit. Throughout three iterations over four years, we used conjecture mapping to reflect on our design considerations when constructing and implementing a culturally relevant chemistry unit. We explain how we cultivated relationships with the community and identified resources that students used to inform classroom activities. We also describe how culturally relevant education relates to the unit and identify areas where we are still growing as we engage in the design process. Through this work, we explain how conjecture mapping helped the design team consider their positionality and how it affected adaptations throughout the project.

5.3 Introduction

“I don’t know what type of information I can provide since this is about science…,” responded Naiyuq to how the interview was framed. Naiyuq is a young Iñupiaq woman who is a part of a movement in her community to reclaim Iñupiat culture in recent years. Naiyuq is also a
traditional Iñupiaq herbologist, telling stories of walking with her grandmother to pick plants in the tundra around Utqiaġvik, Alaska that can be stored and eaten in the Winter or used for medicinal purposes. Her process of identifying plants is scientific in nature, considering defining characteristics and consulting notes in a journal that is passed on between generations. However, when considering how science is taught in school, she mentions,

"We go through school and learn a bunch of things that have nothing to do with anything outside of school... Dissecting cats and pigs – that has nothing to do with our culture. We could bring a caribou in, and we can show you that we know the Biology. We can show you how to carve... we know the different parts and know what's edible and what's not."

Naiyuq’s thoughts are similar to students who struggle to identify with science, as it is presented in the classroom, yet engage scientifically throughout their everyday lives. With this in mind, it is important to consider ways to connect the two worlds.

Recent curricular reform efforts in science education focus on student engagement in authentic science practices alongside learning content in the classroom (National Research Council, 2012). These practices help students contextualize scientific learning with actions that reposition students as agents in the scientific process (Ford & Forman, 2006). However, these practices privilege a Western perspective on scientific knowledge construction, which makes it difficult for students from non-Western cultures to engage in scientific topics (Bang & Medin, 2010; Medin & Bang, 2014). Culturally relevant education (CRE) is a framework that recognizes students’ cultural assets to inform a classroom environment that affirms academic content while affirming students from diverse backgrounds and cultures (Aronson & Laughter, 2016; Gay, 2010; Ladson-Billings, 1995). Aronson and Laughter (2016) pay credence to and summarize the researchers who studied and expanded upon this framework since its inception in 1995, depicting their work in four tenets (Table 5.1).

While examples of CRE in science education are increasing (Bang, Faber, Gurneau, Marin, & Soto, 2016; Barton & Tan, 2009, 2010; Calabrese Barton et al., 2021), design processes are generally contained in the methods section to make room to describe the findings generated in a design. This creates a “black box” phenomenon, where readers wonder how the researchers structured and supported their specific innovations, who they worked with to ensure the success of their work, and specifics about the contexts in which they implemented their design. Especially since many of the researchers who engage in design possess differing cultural value sets than the students, teachers, and communities they design for (Costanza-Chock, 2020;
Esmonde & Booker, 2016). Focusing specifically on considerations that the designer made during the design and implementation process could serve as a guide for those who wish to promote the design of justice-oriented science curricular materials. This paper details the design and implementation process used during a four-year collaboration between Iḷisaġvik college, a Tribal College in Utqiagvik, AK, and the University of Michigan (UM). In this work, we engaged in a collaborative design process to learn about how culture, context, and place influence the design of a culturally relevant snow chemistry unit. Throughout this time, we tracked considerations we made to adapt our initial design based on contextual features, student data, and stakeholder (e.g., instructor, student) feedback. We also examined our positions as outsider researchers who build relationships with a community with an extensively studied Indigenous population. In doing this, we aim to “open up the black box” of designing with a culturally-relevant lens, considering the process of how we adapted our curricular materials from our initial design through multiple iterations, to affirm that Iḷisaġvik students’ cultural funds of knowledge (Moll, Amanti, Neff, & Gonzalez, 1992) can be integrated while learning Western science.

5.3.1 Collaborative Design Methodologies

Curriculum design is complicated. As an innovation moves from design to implementation, it must hold in tension multiple expectations from various stakeholders. For instance, designers should base their work on current curricular reform efforts (National

<table>
<thead>
<tr>
<th>Tenet 1</th>
<th>Cultural References and Academic Concepts</th>
<th>A culturally relevant educator takes steps to understand their students’ cultures and contexts, actively building curriculum around these aspects of students’ lives.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenet 2</td>
<td>Critical Reflection</td>
<td>A culturally relevant educator provides opportunity for students to reflect on how course material relates to their culture, community, and society.</td>
</tr>
<tr>
<td>Tenet 3</td>
<td>Cultural Competence</td>
<td>A culturally relevant educator recognizes that not all students of the same demographic share the same experiences and resources, that the classroom is likely filled with people from diverse cultures, and that science content has its own culture and builds opportunities to reflect on and incorporate multiple worldviews from within the classroom.</td>
</tr>
<tr>
<td>Tenet 4</td>
<td>Critique of Discourses of Power</td>
<td>A culturally relevant educator recognizes systemic injustices that affect non-majority students and finds ways to identify, discuss, and promote action within the classroom.</td>
</tr>
</tbody>
</table>
Research Council, 2012; Penuel & Fishman, 2012) while considering their design imperative. They also need to consider the context in which the innovation will be implemented, navigating important, systems-level variables, such as administrative initiatives, available resources, and classroom structure (Allen & Penuel, 2014; Henderson & Dancy, 2007). When a design moves towards implementation, understanding the beliefs and practices of instructors (Fletcher & Luft, 2011) and considering viable structures for supporting adaptation and use of innovations could ensure the curriculum transfers with enough fidelity to support what makes the design effective (Penuel & Fishman, 2012). During implementation, considerations of the students, culture, and community could also determine whether an innovation is feasible and relevant to the learners (Aronson & Laughter, 2016). This list is non-exhaustive and demonstrates a few of the thoughts, amongst many possibilities, a designer could consider as they conduct their work. Often, this leads to curricula constructed from the designers’ perspective without a true partnership with stakeholders. Claims of design efficacy are couched with the nuance of the design process: for whom do we design? what values do our designs convey? how does power influence whose voice is considered during the design and implementation process? is what we design relevant to our students’ lives and allow them to engage meaningfully in the curriculum?

Collaborative design processes (Penuel et al., 2020) recognize the complex ecosystem that surrounds the designer as they go about their work. This family of design approaches share “new ways to organize the enterprise of education research to be more of a “two way street” between researchers and key stakeholders in the improvement of practice” (Penuel et al., 2020, p. 631; Tseng, Easton, & Supplee, 2017). These practices call upon a range of stakeholders, from community members, teachers/instructors, students, administration, and researchers, to be involved in the design process and inform what gets taught in learning environments. Penuel et al. (2020) propose a series of principles that guide the collaborative design process. These include recognizing the need for designs to provide practical value to participants and their organizations or communities. Indeed, we (researchers) are invited guests to the communities where we work and cannot automatically assume that our intentions are practical (or even beneficial) for the people we work (Medin & Bang, 2014; Smith, Tuck, & Yang, 2018). As a result, we (researchers) should continuously seek and adapt our designs to align with what our stakeholders deem as practical.’ The principles of collaborative design also recognize that we (researchers) are not the sole parties involved in the implementation of a design and should seek
to support the agency of participants within their system to recognize the full contributions of participants’ work to the success of a design. The collaborative design process produces knowledge about learning environments with special attention to context and is iterative and collaborative with multiple stakeholders. The multiplicity of voice decenters the designer’s perspective and provides contextual means to adapt and sustain innovations in specific learning environments.

Considering community value sets when designing for CRE (Aronson & Laughter, 2016) and the socio-political history of non-majority communities around the United States (Esmonde & Booker, 2016), collaborative design processes resituate the power dynamics of design so that many stakeholders have a voice and agency to control the outcome of the innovation. This distribution of power allows a natural pathway for researchers to learn about and engage deeply with the communities in which they partner. In providing detail about how a researcher designs for cultural relevance, we can reveal structures that others could consider when engaging as outsiders in non-majority communities.

5.3.2 Conjecture Mapping to Capture Design

The inherent complexity of design research makes it difficult to study and communicate. The highly contextual nature of data muddles whether a specific innovation led to intended outcomes. Sandoval (2014) proposes the use of conjecture mapping as a way to organize design research systematically. Conceptualized in response to the critique that design research can be too reflective in nature, conjecture mapping “specifies theoretically salient features of a learning environment design and maps out how they are predicted to work together to produce desired outcomes” (Sandoval, 2014, p. 19). Conjecture maps guide the testing of specific theories about teaching and learning in a project, helping the researcher pay attention to improving educational practice while growing our understanding of how people learn in specific contexts.

The conjecture map contains four main components (Figure 5.1). The first is the conjecture, which is the theory that undergirds the learning process the researchers study in a particular context. For instance, using CRE in the design process will allow students to better identify with Western science as they engage in the curriculum. Next, the embodiments are the design features that are implemented in the learning environments characterized by the conjecture. For example, a community Elder visiting the classroom to talk to students about
issues of concern in their community is an example of an embodiment of CRE because the design team is incorporating outside resources to structure discussions in their classroom. Embodiments contain three categories: tools and materials, task structures, and participant structures. Thirdly, mediating processes detail how the users interact with the design, which is categorized as observable interactions and participant artifacts. For instance, video data of students asking the Elder questions during the visit allow us to consider how students engage with the design. The mediating processes eventually shed light on whether the desired outcome is produced. This fourth category helps the researcher understand how the initial conjecture was enacted in their design and can guide how the design is adapted for future iterations.

Conjecture mapping is gaining traction in design-based research to track considerations made as an innovation moves from design to implementation (Boelens, De Wever, & McKenney, 2020; Lee, DeLiema, & Gomez, 2022; Wilkerson, 2017). In a call to center issues of equity in design-based research (Bang & Vossoughi, 2016), researchers are examining how their designs contribute to social transformation and offer a space where participants can engage in authentic collaboration and participation (Gomez, Kyza, & Mancevice, 2018; Gutiérrez & Jurow, 2016). The collaborative and iterative nature of design-based research provides researchers and participants clear markers of transformation over time that build towards theories of learning, offering specific areas where researchers’ and participants’ diverse conceptions of equity, teaching practice, and content can be shared (Boelens et al., 2020; Gutiérrez & Penuel, 2014; Lee

![Figure 5.1. Overview of a conjecture map from Sandoval (2014).](image)
et al., 2022; Nasir & Vakil, 2017; Philip & Azevedo, 2017; Wilkerson, 2017). Lee et al., (2021) suggest the addition of a guiding conjecture that centers equity on the original conjecture map, studying how various stakeholders’ perspectives of equity shift while designing a computer science unit. While not an iterative process, the researchers demonstrate “how equity conjectures—statements about how to remedy socially and historically constructed injustices through learning designs—can be integrally connected to the artifacts and processes used during co-design” (Lee et al., 2022, p. 95). The recognition of grounding equity as a separate conjecture allows for the examination of our actions as designers in how we can better serve our participants.

5.3.3 Research Questions

Within the specific context our partnership between Ilisaġvik College and UM, researchers and instructors collaborated to design a snow chemistry unit for introductory science courses. We operated with the overarching design question: How do culture, context, and place inform the development of a culturally relevant snow chemistry unit? Thoughts on this particular topic are represented in a previous manuscript (Spencer et al., 2021). However, the design question informs the focus of this study. To candidly describe how we designed the unit, we utilized conjecture mapping (Sandoval, 2014) to track how our design shifted over four iterations considering the research question: How can we use conjecture mapping to track how students engage in the tenets of CRE within the snow chemistry unit? In doing this, we provide a rich account of considerations, both cultural and otherwise, we made to design the snow chemistry unit, as well as some areas we are still growing as a collaboration. Recognizing the cultural divide that many designers face as they work in diverse settings, structures that our team utilized and areas we continue to learn could serve as a building block for reorienting the power dynamics that are latent in the design process (Costanza-Chock, 2020; Esmonde & Booker, 2016; Lee et al., 2022).

5.3.4 Study Context

To construct relevant teaching material for classrooms, the designers need to understand and appreciate the social and cultural backgrounds of the students interacting with the design. If the curriculum designers come from different social and cultural backgrounds than the students,
immersive experiences are important to appreciate the students’ culture and history. Regarding the development of the culturally relevant curriculum in this project, the course designers either came from or immersed themselves in the local and cultural contexts in Utqiaġvik. Given the importance of context in collaborative design, we introduce the local, cultural, and historical context in Utqiaġvik.

5.3.5 Historical Context

The Iñupiat village of Utqiaġvik, Alaska (also known as Barrow) is located at the northernmost point in the United States on the coast of the Arctic Ocean at the confluence of the Chukchi and Beaufort Seas (Figure 5.2). Iñupiat have lived on the Arctic coast for thousands of years (Dixon Jr, 1975; H. L. Smith, Rasic, & Goebel, 2013) and have continuously occupied the specific location of Utqiaġvik for at least 1500 years to hunt for whales (Carter, 1966; Jensen, 2009; Stanford, 1976). Ocean currents that run near shore create leads (e.g., cracks that have open water near sea ice) close to the beach during the winter and spring, allowing local Iñupiat to access a bounty of resources, such as marine mammals, birds, and fish. Although the Iñupiat harvest a wide variety of sea mammals, land animals, plants, fish, and birds, the locals of Utqiaġvik focus primarily on hunting bowhead whales that travel along open leads in the ice during their springtime eastern migration. For this reason, Utqiaġvik is considered one of the most strategic hunting locations in the Arctic, making it prime Iñupiat real estate. Knud Rasmussen, a famous Arctic explorer, remarked after traveling on dogsled from Greenland to Alaska, that “Pt. Barrow has always been one of the main centers for the Eskimo whaling industry” (Rasmussen, 1927, p. 305).

Being so far north, the Iñupiat whaling communities on the North Slope, the region of Alaska where Utqiaġvik is located, were generally left alone by European and Euroamerican explorers and colonizers until the mid-19th century when commercial whaling boats began
entering the Arctic Ocean to harvest large quantities of bowhead whales and walrus. For instance, roughly 200 commercial whaling ships entered the Arctic Ocean in 1852 through the Bering Straits (Bockstoce & Burns, 1993, p. 567), killing thousands of whales per year. Commercial whalers established onshore whaling stations in Utqiaġvik and several other locations along the Arctic Ocean coast during the second half of the 19th century. Eventually, the commercial whaling industry in the Arctic crashed due to depleted populations, dangers of operating in sea ice, and the development of fossil fuels to replace whale oil products. Federal and other foreign entities also used Utqiaġvik as a logistical hub for nearly 200 years. For instance, the H.M.S. Plover, one of the first vessels to search for the Arctic explorer Sir John Franklin, spent two years (1852-1853) overwintering in the Elson Lagoon near Utqiaġvik (Davis, 1991). From 1881-1883, during the first International Polar year (IPY1), the first academic scientists built a research station in Utqiaġvik to observe and measure environmental and weather conditions and to also learn about flora, fauna, and local Iñupiat (Krech III, 1989, p. ix; Murdoch, 1892).

5.3.6 Scientific Context

The North Slope region was targeted for its oil reserves in 1917 when the U.S. government recorded oil seeps in Smith Bay, east of Utqiaġvik (Norton, 2001, p. 29). In 1921, 23.6 million acres of land surrounding Utqiaġvik were converted into the Naval Petroleum Reserve – 4 (PET-4) to provide oil to the U.S.’s new gas-powered naval fleet (Reed & Ronhovde, 1971). It wasn’t until the 1940s, during WWII, that the federal government began the process to extract oil from the North Slope. To do this, they built the Naval Arctic Research Laboratories (NARL), a 1000-man campus to support the development of cold-weather oil exploration and extraction technology. Following the end of WWII, the NARL campus was converted into an Arctic research logistical campus, run by the Office of Naval Research (ONR) and the University of Alaska, Fairbanks (UAF). Throughout the 1950s, 60s, and 70s, NARL was a center of international Arctic research — a bibliography published in 1973 listing scientific publications based out of Utqiaġvik totaled 2,426 publications, with over 4,000 contributing authors (Erickson, 2020; Gunn, 1973).

Most, if not all, Arctic research based and conducted out of NARL was influenced or inspired by the knowledge shared by the Iñupiat whalers of Utqiaġvik. NARL provided hundreds
of jobs annually, 60 percent of which were filled by local Iñupiat (Norton, 2001). Upon reflecting on the history of NARL, a historian recognized that “many scientists (at NARL) owe their survival, the success of specific projects, and even their ultimate career success to their Iñupiat guides, who shared what they knew about the Arctic” (Brewster, 1997, p. 279). Eventually, due to several factors, NARL was shut down and local organizations assumed ownership of the campus, converting the infrastructure to serve local needs. Today, the NARL campus includes Iḷisaġvik College, North Slope Borough Department of Wildlife Management (NSB DWM), multiple housing options for locals and visiting scientists, and the Barrow Arctic Research Center (BARC), a relatively new $110 million scientific research facility. The Ukpeaġvik Iñupiat Corporation (UIC) owns most of infrastructure and land at NARL, operated by UIC’s science logistics company, UIC Science. Today, Iḷisaġvik College, the NSB DWM, and UIC Science carry on the historical legacy of fruitful relations between scientists, educators, and locals.

5.3.7 Socio-Political Context

It is no coincidence that the local Iñupiat own and operate the NARL campus. Nor is it a coincidence that the local Iñupiat own and operate Alaska’s largest private business, the multi-billion-dollar company Arctic Slope Regional Corporation (ASRC), headquartered in Utqiaġvik. It’s also no coincidence that the local people tax the oil companies nearly half-a-billion dollars each year through the North Slope Borough, also headquartered in Utqiaġvik. It all had to be fought for, tooth and nail, by the local population. When Alaska became a state in 1959, the new state government (e.g., the State of Alaska (SOA)) was given 25 years to select 130 million acres of land, roughly one-third of the landmass of Alaska. The SOA constitution also gave locally formed boroughs relatively extreme taxation and zoning authority. At this time, the dispute over Indigenous title to the land was never addressed, and Native peoples across Alaska united around the invasion and occupation of their ancestral lands. The SOA and various federal entities divided the land and targeted profitable resources without regard for local Native peoples. For example, Project Chariot included plans to use atomic bombs to construct a large deep seaport near the village of Point Hope, one of the longest continuously inhabited places in North America. The U.S. Atomic Energy Commission and the State of Alaska conspired to do this without any engagement with the local Iñupiat (O’Neill, 2007).
Across the state, under the leadership of Charles Etok Edwardsen and other leaders, Alaska Natives fought back against large-scale projects focused on profitable exploitation by the SOA, the federal government, and private companies. As a result of the land ownership disputes, the U.S. Secretary of the Interior enforced a “land freeze” in 1968, stopping all land leasing and ownership transactions in Alaska, including ongoing SOA land selections and federal land leases to oil companies, until there was a legal resolution between Alaska Natives and federal entities regarding Indigenous title to ancestral lands. This led to the Alaska Native Claims Settlement Act (ANCSA) of 1971, which lifted the land freeze in exchange for the extinguishment of aboriginal title to lands, creating twelve regional corporations (e.g., ASRC) and over two hundred village corporations (e.g., UIC). It is important to note that the only region in Alaska to vote against the passage of ANCSA was the North Slope because the agreement forced all regional corporations to share seventy percent of profits made from subsurface resources (e.g., oil, gold). In essence, the North Slope Iñupiat were forced to create their regional corporation, ASRC, and the various village corporations, including UIC for Utqiaġvik. Shortly after following ANCSA, North Slope leadership used State law in their favor, applying for the creation of the 59-million-acre North Slope Borough (NSB). The SOA and oil companies disputed the creation of the NSB due to the potential zoning and taxation power local Iñupiat would be given over the oil fields on SOA and federally selected lands on the North Slope. The courts ruled in favor of the creation of the NSB, and the local government taxed the oil companies tens of billions of dollars to fund local infrastructure and support their population (Knapp & Morehouse, 1991).

5.3.8 Context in Relation to Education

The formation of the NSB led to the community “regaining control of the education of [their] children … examining whether or not [their] school system is truly becoming an Iñupiat school system” (Hopson, 1975). To the Iñupiat people, like many other Indigenous communities (Bang et al., 2016; Bang & Medin, 2010; Castagno & Brayboy, 2008; Treuer, 2019), local control of their education system was crucial for the people to pass on their traditional knowledge system, which “is extended and depend by allowing young students to personally experience phenomena in the environment while being guided and kept safe by community members” (p. 364, Written by Erickson, Spencer, 2021). This signaled a massive shift from the
previous generations’ children being forced to learn Western Culture in boarding schools (Chance & Chance, 1990; Dunbar-Ortiz, 2014) to a reclamation of how they teach their youth (Hopson, 1975). The formation of the North Slope Borough allowed Utqiaġvik to build an education system for their community that included a school district and Iḷisaġvik college, Alaska’s only Tribal College. Throughout this period, community members in the education system collaborated to clearly define Iñupiat values and how they relate to material that is taught in schools (Zanotti et al., 2020). Within this study, we recognize and affirm the continued efforts of the Utqiaġvik community to teach and preserve Iñupiat culture to all people within their community.

How do the historical, scientific, and socio-political context impact the creation of culturally relevant curriculum in Utqiaġvik? The connections are numerous. The NSB uses their tax base to pay for Iḷisaġvik College operations, providing free tuition to all NSB residents and Alaska Natives around the country. Iḷisaġvik College provides culturally relevant education to their community while preparing their students with training for careers within and outside of Utqiaġvik. NSB also is the largest provider of employment, offering 60% of all jobs across North Slope villages (Knapp & Morehouse, 1991). UIC, the local village corporation created under ANCSA, owns the NARL campus, which they had to fight for when the Navy bid for contractors to demolish the campus in 1981 (Norton, 2001). UIC eventually gained the title of the campus in 1989 (Kelly & Brower Sr, 2001). UIC also owns and operates the BARC and the 7,400-acre Barrow Environmental Observatory (BEO), which draws hundreds of scientists to Utqiaġvik, most of whom hire the local UIC Science staff, who are local Iñupiat hunters and whalers, to help and assist their research. This situation creates cross-cultural dialogue and learning, leading to the co-production of knowledge. For example, the entire idea for the design of this unit was conceptualized through conversations between visiting scientists from UM and local UIC Science staff, including the authors of this paper.

5.4 Methods

The methods section is divided into four subsections describing our design, implementation, and analysis processes. We begin our methods section by discussing contextual considerations that we made due to the unique characteristics of the Utqiaġvik community. We
then discuss how we initially designed the snow chemistry unit, which includes our initial conjecture map. After that, we disclose how we supported implementation throughout the collaboration process. The final subsection describes our data analysis process.

5.4.1 Contextual Considerations

We affirm Indigenous research methodologies (Brayboy, 2005; Chilisa, 2012; Kovach, 2010; Wemigwase & Tuck, 2019; Windchief & San Pedro, 2019) in our approach towards design, as we hope to move “beyond damage research narratives that limit possibilities and hope for Indigenous peoples and communities and move towards desire-based research that recognizes…and revitalizes the power already held in communities” (Windchief & San Pedro, 2019, p. xvii). Recognizing our positionality (St. Louis & Calabrese Barton, 2002) as outsiders in the community, we uphold the need to prioritize relationships and stories of the community over research outcomes and our design agenda. Because of this, we defer to the suggestions of community members and Elders to reinforce communal agency. The identities of the project

| Iteration 1 | Semester | Course(s) | Number of Students | Student Self-Identified Cultures | Video Recordings (hours) |
|-------------|----------|-----------|--------------------|--------------------------------|--|------------------|
| Iteration 2 | Spring 2020 | Climate Change on the North Slope | 2         | ᤕฏpiiaq, White | Planning: 9.5 | Class: 9.75 |
| Fall 2020   | Chemistry in Society | 6         | ᤕฏpiiaq, LatinX, Filipino, White | Planning: 7.5 | Class: 29.75 |
| Iteration 4 | Fall 2021 | Introductory Chemistry | 2         | ᤕฏpiiaq, LatinX | Planning: 7.5 | Class: 18.75 |
|            | Indigenous Sciences | 2         | ᤕฏpiiaq, White | Class: 8.25 |
team inform their contribution to the project and the cultural lenses that undergird our perspectives and analysis. Throughout this article, we intentionally use specific labels to describe members’ contributions at various points of the project (Table 5.2).

Iljisaġvik College is the only Tribal College in Alaska and seeks to provide post-secondary classes in a “learning environment that perpetuates and strengthens Iñupiat culture, language, values, and traditions” (Iljisaġvik College, 2022b). While located in Utqiaġvik, the College serves a diverse population of students (Table 5.3). For instance, while the college is “Unapologetically Iñupiat” (Iljisaġvik College, 2022a), the students come from a range of cultures that are Indigenous (e.g., Iñupiat, Alaska Native, other Indigenous-American) and non-Indigenous (e.g. Filipino, LatinX, White). The college also offers robust distance engagement opportunities that serve students from remote, rural locations in Alaska along with students from the contiguous United States. These remote platforms also promote engagement for in-person students during the harsh winter. Class sizes are relatively small (e.g., 2-10 students), with many students transferring to four-year institutions once they complete their Associate’s degree at Iljisaġvik. The professor is the only science faculty at the college, teaching a range of traditional science courses (e.g., Chemistry, Biology) alongside science-oriented courses for non-science majors (e.g., Climate Change, Indigenous Science). She also engages students in culturally relevant science activities that use Western science techniques to analyze aspects of Traditional Knowledge. For instance, in her Biology classes, students collect Traditional plants from around their community and extract the medicinal ingredient using Western lab techniques (Nicholas-Figueroa, L. et al., 2015; Nicholas-Figueroa, L. et al., 2017; Spencer et al., 2021).

### 5.4.2 Design Process

The UM team visited Utqiaġvik in the Spring of 2019 to acquaint ourselves with the culture and context of the community. Prior to arriving, the UM team considered interactions with the community and culturally sensitive methods of communicating with Indigenous people from an Anthropology professor at Iljisaġvik. The goal of this preparation was to recognize the latent power dynamic inherent within the research process and the privilege of learning others’ knowledge they choose to share (Tuck & Yang, 2014). During this visit, the UM team prioritized building relationships with community members, staff and students at Iljisaġvik, and teachers and administration at the local K-12 schools. All participants consented into the interview process.
To learn more about the people of Utqiaġvik, specifically how they engage in traditional practices and their perspectives on science (from Indigenous and Western perspectives), the researchers conducted semi-structured interviews after being invited by the participants to ask them questions about their culture. The researchers met many people through established relationships (e.g., our collaborators) or encounters during cultural experiences (e.g., visits to the Iñupiat Heritage Center). During the interview, the researchers asked participants to describe their experiences engaging in Traditional practices (e.g., hunting, whaling) before asking about their thoughts on science and formal educational experiences. While the design team used most interviews to inform the design process, we identified specific interviews that captured patterns in the early data (e.g., the disconnect between science in their daily life and formalized schooling). The researchers asked if they could use the participants’ example in portraying our project to the research community and asked for pseudonyms. Naiyuq is an example of a community member interview that personified a pattern.

During our first visit, the UM team learned about the context of Iḷisaġvik through classroom visits, learning about the beliefs and practices of the professor, and interviewing students. After their arrival, the UM team visited the professor’s classroom, taking notes on her methods of instruction, how she engaged students, and how students interacted in the classroom. Through these initial visits, the UM team met the professor’s colleagues and were invited into their classroom spaces where we viewed how other subjects were taught. The researchers also interviewed the science professor’s experiences and background as well as her perspectives on teaching and learning (Luft & Roehrig, 2007) to align ourselves with her classroom practices. Throughout our classroom visits, the researchers interviewed eleven students from various backgrounds and ages in multiple subjects to learn about their experiences with science in formal and informal learning settings.

Recognizing that students’ science experiences in higher education are informed by their experiences in secondary classrooms, the researchers intentionally sought connections in the local school district. To establish connections, the researchers visited schools during community events (e.g., basketball games), introduced ourselves to the school administration, and explained the nature of our project. The administrators connected researchers to science teachers at the middle school and high school classrooms and the teachers invited us to two science classes in
each building. During our visit, the researchers talked with the science teachers and learned about their perspectives on implementing Iñupiat knowledge systems alongside the NGSS in their classrooms, capturing our thoughts on these experiences through memos.

At the end of the visit, the project team hosted a social event with a public presentation for the community. During this presentation, we outlined our design plan for the student-driven research project and asked for feedback from the community. The community feedback focused on community resources we could incorporate into the project and how to increase involvement with Elders in the community. We worked with the UIC-Science outreach coordinator (co-author KSE) to ensure activities and public presentations correlated smoothly with other local science outreach and community engagement projects.

Data collected and experiences from the first trip framed a collaborative design workshop at UM in the Summer of 2019 that included the professor at Iñupiaq and the UM team. During this workshop, the design team brainstormed ways for students to participate in snow chemistry science practices while reflecting on their cultural identity. Throughout the workshop, the design team constructed activities where students identify and reflect upon community resources to inform their project. Students then develop a research question aligning with the cultural and scientific elements of the project. The design team also discussed ways to include interactions between students and community members in various components of the project (Godínez Castellanos et al., 2021). Some members of the UM team walked the professor through the uses of Ion Chromatography and the protocol for titration that would measure inorganic ion concentration in snow samples (May et al., 2018). All interactions during the workshop were recorded. The design team frequently consulted the notes and recordings from the Spring and Summer 2019 visits while developing the snow chemistry unit, and revisited these recordings throughout all iterations to remind ourselves of specific decisions that informed the unit. After the workshop’s conclusion, we collaborated as a project team to ensure that the unit was responsive to cultural values and the professors’ classroom context.

The design process yielded a snow chemistry unit where students engage in scientific practices in a manner that relates to their culture and community (Figure 5.3). The unit is split into three sections: information gathering and developing a research question, collecting and analyzing snow samples, interpreting data, and communicating results to the community. The first section engages students in exploring knowledge about snow and ice from within their
community. This includes interviewing community members and listening to stories about changing snow and ice in their community. Students also learn about the Western Science perspective through a snow chemistry guided inquiry activity informed by the Process-Oriented Guided Inquiry Learning pedagogy (POGIL) (Moog & Spencer, 2008). Students then summarize the knowledge that they learned from the early activities and develop a research question to study. The second section focuses on students’ collection and analysis of snow samples from around their community. Before collecting their samples, students develop snow sampling protocols based on their research questions. Students also present their experimental protocols along with the knowledge that informed their research question to a science professor who conducts snow chemistry research in Utqiaġvik. The third section includes the students’ interpretation of their results and the presentation back to the community. Students’ interpretation includes graphing their chloride concentration in a way that is guided by their research question. Students then work in teams to construct presentations to tell the story of their research project during a community meeting. Further details of the snow chemistry unit can be found in a previous publication (Spencer et al., 2021).

Within the initial design process, the design team accommodated for the diversity of students at Ilisaġvik in two ways. First, over one-third of students who participated in this study were not geographically located in Utqiaġvik. For the students located in other parts of Alaska, snow and ice were still relevant to their context, leading to a similar participation as the in-person participants through Zoom. While these students could not collect and analyze physical samples, they could still engage in all other parts of the unit from a cultural perspective. The design team asked students located in the contiguous United States to develop research questions relevant to their particular context. For instance, an Indigenous student from the Pacific Northwest traveled to their reservation, asked Elders about their interactions with snow and ice.
and reflected on the experience. Whenever possible, the design team tried to connect information learned from this interaction to students’ sampling protocols in Utqiaġvik. The second accommodation recognizes that not all students in our unit come from Iñupiat culture. These students could pursue research questions that were culturally salient to them, which led to incorporating local resources alongside traditional knowledge in the types of information students gathered (Spencer et al., 2021).

5.4.3 Initial Conjecture Map

The purpose of a conjecture map is to track both considerations made by the design team as well as participants’ interactions with designed components in their relationship to a higher-level conjecture (Figure 5.1). The researchers constructed the initial conjecture map (Figure 5.4) as we designed the unit after the summer workshop. Our project explores the students’ engagement as they conduct a scientific research project relating traditional Indigenous knowledge and Western science. As such, we define our overarching conjecture as: students can better identify with science when a curriculum is constructed that affirms their worldview. This conjecture is supported by literature in cultural relevance (Aronson & Laughter, 2016; Ladson-

*Figure 5.4* Initial conjecture map, summarizing our initial design elements (embodiments), considerations for participant interactions with the design (mediating processes), and intended outcomes as they relate to Aronson and Laughter (2016).
Billings, 1995) and decolonizing spaces (Cajete & Bear, 2000; Medin & Bang, 2014; L. T. Smith et al., 2018). Our outcomes align with the tenets of CRE as identified by Aronson and Laughter (2016) (Table 5.1). For instance, as students engage in a unit that explores multiple perspectives within a science classroom, they may connect these perspectives to the skills they are learning in the classroom (Aronson & Laughter, 2016; Medin & Bang, 2014).

**Embodiments** are defined as the designed components that align with the overarching conjecture to reach the outcome (Sandoval, 2014). In other words: what is the design intended to look like? Following are the four categories of embodiments and how we defined them in our project. Tools and Resources are ways we engaged students in bringing external (e.g., non-classroom) resources from their cultural and local expertise into the project. Task Structures are

<table>
<thead>
<tr>
<th>Embodiment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tools and Resources</strong></td>
<td>Components of the unit connecting students to resources outside of their classroom, both cultural and otherwise, that characterize their worldview (Moll et al., 1992) (Barton &amp; Tan, 2009). Designed actives within our unit include Elder storytelling about snow and ice, students interviewing community members, or interactions in other assignments where students assert their worldview in combination with the objective of the activity.</td>
</tr>
<tr>
<td><strong>Reflective Prompts</strong></td>
<td>Classroom activities, both written and verbal, where students reflect upon what they are experiencing in the activity, their perspectives and worldviews, and summaries of their learning throughout the project (Davies, 2012). Specifically, each activity as outlined in the unit has an embedded reflection where students choose prompts to guide their thoughts. We designed summary activities, such as the information gathering assignment and the summarizing knowledge and developing a research question activity, so that students would weave knowledge sources as inspiration for their project.</td>
</tr>
<tr>
<td><strong>Community Presentation</strong></td>
<td>The intended capstone activity for the end of the course where students and the design team interact with the community to present their findings and gather feedback for future iterations. All components of the unit are preparation for this activity, and we view this as a space where students present the knowledge they learned that inspired the research question, their data collection protocol, their interpretation of the results, and implications for their work.</td>
</tr>
<tr>
<td><strong>Data Collection and Analysis</strong></td>
<td>The student-led scientific process of exploring their research question, with many of the structures constructed to embody the NGSS Science and Engineering Practices (National Research Council, 2012). Within the unit, this includes the snow sampling experimental design protocol, the chat with a research scientist activity, the snow sample collection, the physical and chemical snow measurements, and the analysis and interpretation of their data.</td>
</tr>
<tr>
<td><strong>Participant Structures</strong></td>
<td>Activity based off of the Process-Oriented Guided Inquiry Learning (POGIL) model (Moog &amp; Spencer, 2008), where students learn scientific concepts through carefully constructed models. In this activity, students learn about the origins of inorganic ions in the snowpack through models developed from primary literature (Domine, Sparapani, Ianniello, &amp; Beine, 2004). In the POGIL mindset, students and the instructor had specific roles: students were to collaboratively work through the models and questions in a packet while the instructor acts as a facilitator, answering student questions through guiding questions.</td>
</tr>
</tbody>
</table>

Table 5.4. Definitions of the design embodiments as they relate to our initial conjecture map, Figure 5.4.
designed classroom activities that engage students in specific perspectives throughout the unit.

*Participant Structures* are ways that we intentionally structured engagement in the actual classroom as a part of the initial design. *Discourse Norms* are defined ways in which participants and/or the design team interacts with the initial designed unit. For the initial implementation, we viewed the design team as external to the processes that occurred within the classroom, engaging with the professor in weekly collaborative meetings. Descriptions of each embodiment can be found in Table 5.4.

*Mediating processes* detail how the participant interacts with the designed embodiments in relation to the intended outcome — in other words, how do the participants interact within the design? We define the two categories of Mediating Processes as follows. *Observable interactions* directly show how the participants’ interactions with the embodiments relate to the intended outcome. *Participant artifacts* are participant products from their interactions with the embodiments as they relate to the intended outcome. Descriptions of each Mediating Process can be found in Table 5.5.

<table>
<thead>
<tr>
<th>Mediating Process</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Observable Interactions</strong></td>
<td></td>
</tr>
<tr>
<td>Video Recordings</td>
<td>The primary way the design team interacted with students. Due to the ubiquitous nature of this mediating process, we mention video recording in the analysis solely when we observe participants interacting with a particular embodiment, which is different from the general data that we collected throughout the course of the project.</td>
</tr>
<tr>
<td>Chat with Research Scientist</td>
<td>Specific observable interaction that we intentionally designed to capture the overlap between multiple sources of knowledge and the Western Science perspective. Multiple embodiments could potentially be linked to this specific interaction depending on students’ engagement leading up to the activity.</td>
</tr>
<tr>
<td><strong>Participant Artifacts</strong></td>
<td></td>
</tr>
<tr>
<td>TK/WS Informed Research Questions</td>
<td>The information students that inform the research question they develop. This mediating process relates specifically to Traditional Knowledge (TK) and Western Science (WS), and can be found in students’ actual research question, their responses to reflective prompts throughout the unit, and the community presentation at the end.</td>
</tr>
<tr>
<td>Student Reflections</td>
<td>The process of students reflecting on snow chemistry unit content in its relation to our intended outcome. These reflections can be both verbal or written as well as prompted or spontaneous.</td>
</tr>
<tr>
<td>Community Feedback</td>
<td>The interaction of community members in the events of the unit, with the intent on providing space for them to influence the direction of the students’ research and the overall project.</td>
</tr>
</tbody>
</table>
5.4.4 Implementation Process

We rely on the principles of Collaborative Design (Penuel et al., 2020) to inform the implementation process due to its focus on incorporating stakeholder goals and interactions as well as mitigating the power balance between all participants in the design process. Also, the focus on adapting curricular resources over multiple iterations based on student data and stakeholder feedback reinforces that the transfer process between two drastically different institutional cultures requires continual support and reflection. We implemented the snow chemistry unit over four iterations between 2019 and 2021 (Table 5.3). The last iteration focused less on researching the implementation process and more on supporting the full transfer of adapted materials into the professor’s classroom. This section will explain how the UM team supported the professor, collected data, and reflected between each iteration to support adaptation. We also include a paragraph discussing how we adapted our unit during COVID.

A major component of the implementation was the support of the professor throughout all iterations. We included brainstorming the structure of support as parts of the initial visit and the design workshop, aligning our approach with what researchers learned during the teacher beliefs interview (Luft & Roehrig, 2007), our memos from classroom visits, and how the professor interacts with students. The UM team also recognized that the professor was the sole member of the science department and was responsible for teaching multiple subjects (e.g., biology, and chemistry) while fulfilling professional responsibilities.

Prior to each semester the snow chemistry unit was implemented, the design team met over multiple sessions to discuss the structure for the semester, identifying common science topics that could be covered through the snow chemistry unit, and considerations based on community events. This included corroborating the syllabus with the snow chemistry unit and planning a rough outline of events. During the semester, the professor and researchers met weekly to consider student interactions with the unit materials from the prior week, adaptations to be made in the current week’s course materials based on student data, and shifts to the overall structure of the semester based on the availability of resources. We structured these weekly meetings roughly as a teacher learning community (Cochran-Smith & Lytle, 1999), where we collaboratively reflected on student data to inspire shifts within the curriculum. All members of the design team collaboratively taught the instructional components during the early iteration to
guide the professor on certain techniques. For instance, one researcher utilized POGIL prior to the project, and therefore modeled the snow chemistry guided inquiry activity during the first iteration. As the implementation progressed, the professor became more comfortable with the resources and the researchers’ role shifted into data collection and adapting the structure. The researchers also managed the course management software utilized by the professor, uploading documents, organizing student data, and providing feedback when requested on specific student artifacts. Researchers also kept detailed notes on the professors’ syllabus about when snow chemistry unit activities occurred over the course of the semester for reference.

Throughout the implementation process, the researchers collected data on all interactions relating to the snow chemistry unit and the initial conjecture map. To collect observable interactions (Figure 5.4), researchers collected video recordings of the collaborative support meetings, classroom sessions relating to the snow chemistry unit, and interactions with students when meeting outside of the course. The professor utilized a specific online conferencing software that also allowed us to collect recordings. During classroom sessions, because of the small number of students, researchers found it difficult to remain unnoticed — students naturally wanted to ask questions and interact with the people collecting data. Therefore, researchers embraced this role as participant-observers and built rapport with the students by introducing ourselves, the nature of our work, and welcoming questions about our backgrounds and the snow chemistry material. Researchers also collected student artifacts (Figure 5.4) relating to the snow chemistry unit, which included written student responses to reflective prompts, drafts of interview protocols as they prepared for the community member interviews, student summaries of community knowledge learned from their interviews, and slides from their community presentation. We intentionally excluded Elder and community member quotes to protect confidentiality and respect the knowledge shared with the project team, focusing instead on student reflections of their interactions.

Between each iteration, the researchers hosted a reflective conversation with the professor to identify salient areas of interaction throughout the previous semester, identify materials or structures that had unintended outcomes, and make adaptations for the upcoming semester. To guide the process, researchers referenced the course syllabus with notes on snow chemistry activities and walked through each activity, asking questions like “how did students engage with this particular activity?”, “how did components of this activity influence the
students’ research question?”, and “is there anything about the activity you would like to shift for the next iteration?” The researchers also looked at student artifacts throughout the unit to approximate if adaptations could be made to support students’ projects. The researchers asked unit-level questions as they noticed patterns in the data. For instance, when researchers noticed that students had difficulty handing in their assignments using one course management software, they proposed other platforms to organize student data and interactions. Once the design team identified potential adaptations, they collaboratively shifted the materials through multiple rounds of feedback. Because we implemented the snow chemistry unit in a wide range of science classes at Ilisaġvik, the design team identified areas where we could supplement scientific material to promote engagement. For instance, Iteration 1 was implemented in a chemistry class for majors, whereas Iteration 2 was implemented in an Indigenous science course for non-majors. Since ionic compounds were not a part of Iteration 2’s regular course curriculum, the design team constructed a lesson to teach ionic compounds so that students could have a base content understanding before proceeding through the unit. The design team met in Utqiaġvik in early 2020 to conduct our first reflective conversation and adaptation process in-person. The other reflective conversations occurred using an online conference platform.

The COVID pandemic affected the design and implementation process in many ways throughout four iterations. Firstly, Iterations 2 and 3 were conducted under social isolation and quarantine guidelines. This presented a series of challenges to the design team, including being unable to meet with community members in-person and unable to collect and analyze new snow samples. We used online conferencing platforms to allow community involvement, where students conducted virtual interviews with community members and Elders virtually visited the classroom. Also, during the project, we could not conduct an in-person community meeting due to COVID restrictions. During each iteration, we tried different mechanisms to bring community members into a virtual space. However, since in-person community meetings are normal events in Utqiaġvik, it was challenging to assemble community members for feedback. Collecting and

![Figure 5.5. Snow sample collection map made by scientific researcher from previous sample collection trip.](image)
Analyzing snow samples proved difficult to adapt: students still made research questions based on their interviews, but used samples and data originating from a researcher that collected samples from around Utqiaġvik and analyzed them using Ion Chromatography (Figure 5.5). This presented a tradeoff where students were unable to collect and analyze their own samples but the data from the research scientists contained a wider array of inorganic ions to include in their analysis. Finally, the design team intended on meeting in Utqiaġvik yearly to collect snow samples with students, reflect on the iteration, and adapt unit materials. Due to travel restrictions, we conducted these meetings virtually.

5.4.5 Data Analysis

As described in the previous section, our data set consists of video recording observable interactions and collecting participant artifacts related to student participation within the snow chemistry unit. The UM team participated using an online video conferencing software. The Ilisaġvik professor set up a laptop in the classroom when activities were in-person—due to the small number of students, most verbal interactions and some non-verbals were captured. We recorded the remote portion using an online video conferencing software. When the class broke up into smaller groups, we placed a researcher in each group to ensure these interactions were recorded. Throughout four iterations, we collected over 100 hours of video-recorded interactions between collaboration sessions, student interactions, and classroom observations (Table 5.3). Researchers collected and organized participant artifacts (e.g., student assignments) using course management software.

Throughout the course of the project, the research team wrote memos (Saldana & Omasta, 2018) to capture insights on what occurred throughout each interaction, thoughts that related to how students participated in Traditional Knowledge and Western Science, and potential adaptations that could be suggested. Memos also served as a way for design team members to reflect on cultural interactions from the perspective of their own positionality (Agbenyega, 2013). The researchers often discussed these researcher-cultural interactions as a group, helping us to characterize our own biases and how they affected the lens in which we conducted our work. For instance, during the UM team’s first visit to Utqiaġvik, many members mentioned the difference in perspective of time between the university context and the community of Utqiaġvik. The UM team recognized that the slowness of pace is often
commented upon by scientists who visit and often leads to cultural tension between the pressure of efficiently using research time and being culturally responsive to community members with whom they interact. As a UM team, we affirmed this tension, kept each other accountable for letting events happen at the pace of the community, and set up structures to onboard new group members who come to Utqiaġvik.

Researchers analyzed the data using a selective coding methodology (Saldana & Omasta, 2018) with the initial conjecture map (Figure 5.4) as the analysis framework. To begin, two researchers independently coded Iteration 1 and Iteration 2 using our conjecture map, where one researcher was responsible for a specific iteration. The process included organizing the data for the iteration chronologically, timestamping each interaction based off events in the data, identifying salient codes related to the initial conjecture map, and constructing a memo at the end of each activity so that researchers could quickly reference specific events from within the unit. Researchers paid close attention to clarifying how they defined mediating processes, embodiments, and the connections between the two. Researchers also recognized when certain embodiments had unintended or missed connections and included them within our codebook to ground adaptation. During this stage of analysis, the researchers met frequently to discuss these codes, refining their definitions and building a consensus for how they interpreted the initial conjecture map (Saldana & Omasta, 2018). After researchers interpreted the codebook in a

<table>
<thead>
<tr>
<th>Conjecture</th>
<th>Embodiments</th>
<th>Mediating Processes</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students can better identify with science when a curriculum is constructed that affirms their worldview</td>
<td>Community Resources</td>
<td>Video Recordings</td>
<td>Tenet 1: Cultural References with Academic Skills</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chat with Research Scientist</td>
<td>Tenet 2: Critical Reflection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant Artifacts</td>
<td>Tenet 3: Cultural Competence</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TK/WS Informing the Research Question</td>
<td>Tenet 4: Critique of Discourses of Power</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Student Reflection</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Community Feedback</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5.6.** Analysis conjecture map example, based off our analysis of Iteration 1 and aligning with examples from Table 5.6.
consistent manner between the researchers, we recoded each iteration to ensure consistent application of the initial conjecture map and constructed analysis conjecture maps (Figure 5.6). Researchers then applied the codes to the third and fourth iterations. Since the fourth iteration focused on supporting the transfer of unit materials to the professor at Ilisaġvik, we focused less on collecting data and more on supporting the professor’s implementation, which is outside the scope of this manuscript. As a result, the fourth iteration dataset was intentionally incomplete and therefore not included in the analysis outside of ensuring consensus remained during the coding process.

<table>
<thead>
<tr>
<th>Mediating Process</th>
<th>Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video Recordings</td>
<td>This is how we collected the data – most direct quotes relating to the conjecture maps are from video recordings unless otherwise specified.</td>
</tr>
<tr>
<td>Chat with Research Scientist</td>
<td>So, I'm watching we had come up with for like, my research question was how does underlaying sources change snow composition. So, kind of our thought on it was when we were trying to come up with places to collect snow one of us had thought of collecting snow from like right on top of the tundra versus right on top of mud and gravel. So, we were wondering how like those different ground places would change the snow right on top of it? In what way? Like would there be more? Like would there be a higher concentration of chloride or higher levels of salt in the snow? Like how would that change it? If it changes it at all?</td>
</tr>
<tr>
<td>Student Reflections</td>
<td>From a knowledge summary activity:</td>
</tr>
<tr>
<td>TK/WS Informing Research Questions (Missed Connection)</td>
<td>Students discussing their question: I got an idea what we could do first for the experiment — We go, and we get a measuring cup right? Like a beaker? We go and we scoop it, and we don't compact it. And then we scrape off the top. And then we melt that snow, and we check the volume of it. So, we take the mass, and we take the volume, crystallized, and the weight and then we do the melt it and get the volume…and then we go right next to a house, and we do it one meter from the house and three meters from the house. And we just do that for two houses, one in town and one outside of town…and maybe one at the beach. And hypothesize that the snow is more moist near water…I don’t know, whatever’s good. Let’s not gather the temperature. That’s too much information. Let’s just get the volume. That’s easier.</td>
</tr>
<tr>
<td>Community Feedback</td>
<td>Not Present</td>
</tr>
</tbody>
</table>
We present an example of our codebook and analysis conjecture map for Iteration 1’s embodiment of community resources in Figure 5.6 and Table 5.6. In the table, rows that are grey are connections between the embodiment and mediating processes and rows that are white are connections that are unintended (e.g., missed connections). We also made analysis conjecture maps for each embodiment for every iteration, labeling blocks that are grey with black connections signifying data that connects the parts of the conjecture map, white blocks with broken grey connections as data that showed missed connections, and black boxes with broken black connections as not present within the specific iterations.

After all iterations were analyzed, researchers revisited the codebook and examined the connections between mediating processes and embodiments, coding for outcomes (e.g., tenets of CRE). During this time, researchers also corroborated our conjectures with memos during implementation observations and notes from the design team reflective conversations between each iteration to identify narrative threads to focus the presentation of our research. We defined the narrative thread as a storyline that spans across iterations in its relation to a specific outcome. This storyline is based off student data in relation to the embodiments, mediating processes, adaptations made between iterations, and eventual outcome. As researchers identified narrative threads, we discussed them as a group and built sequential conjecture maps based on the labeling scheme in our analysis conjectures (Figure 5.6). As the researchers reached consensus, we presented the narrative threads to the project team for feedback and affirmation of the identified focal points of the research. We then organized the presentation of our results around these narrative threads.

5.5 Results

To explore how we utilized conjecture mapping throughout the project, our results section overviews the data collected throughout each iteration as it relates to Tenet 1 of CRE (cultural references and connections to academic skills and concepts). We report on the first three iterations, as we aligned data collection with our initial conjecture maps to ground systematic adaptation of our unit. While a fourth iteration was collected, our focus was on supporting transfer of the materials to the Ilisaġvik College professor. We split each section into four subsections. The Context of Iteration details pertinent contextual information to offer insight into iteration-specific details that affected the implementation, including participant information,
timings of the unit, and accommodations made for students. The *Embodiments and their Connection to Tenet 1* details the narrative threads that researchers identified that related to how students interacted with design embodiments to connect cultural references and academic skills and concepts. This section includes how the narrative threads relate to the conjecture maps. The *Embodiments and Missed Connections* section discusses specific areas where the embodiments did not connect to the outcomes. Finally, the *Summary and Adaptations* section outlines key learning points of the project team for the iteration and specific adaptations that we made after reflecting on missed connections to align the design embodiments more closely with the desired outcome.

### 5.5.1 Iteration 1—Context of Iteration

We implemented the first iteration of the unit in an introductory chemistry course at Ilisaġvik College in Fall 2019. The course was a part of a program intending to help students prepare for various health careers. Seven students from a diverse range of backgrounds, ages, and cultures (Table 5.3) participated in the course. One student lived in the contiguous United States and another student needed a similar accommodation due to the nature of their work. We engaged distance students by remotely including them through all class proceedings, allowing them to consider sources of knowledge and research questions within their local context alongside what they learned through Utqiaġvik community members.

As mentioned by the professor in the design process, this course held in tension the goals of covering the course objectives with implementing the snow chemistry unit. Our response to this concern involved constraining the time we implemented the unit to the latter half of the course. Throughout each week of the course, the design team discussed ways to support implementation and made shifts accordingly. For instance, the Elder who volunteered to talk to the class had other commitments occur during his scheduled time, resulting in the decision to rearrange the unit progression to accommodate the Elder’s schedule. The amount of content associated with the course alongside the later start of the snow chem unit caused the unit to end early without students analyzing data and sharing their results with the community. Figure 5.7 outlines the conjecture map for Tenet 1 of CRE for Iteration 1.
5.5.2 Iteration 1 – Embodiments and their connection to Tenet 1

Throughout the first iteration, students used reflective prompts to involve community resources in multiple activities (Figure 5.7a). For example, students interacted with an Elder whaling captain and planned. They planned and executed interviews involving community members focusing on snow and ice, both of which were planned activities within our design. During the classroom session where students talked to the Elder, much of the discussion centered on changes in whaling practices and shifts in ice floe patterns while whaling. Students then reflected on these instances using the information gathering assignment. For example, a student self-identifying as Iñupiaq mentions:

Some future implications [for me] are how fall whaling will continue. This year our community didn’t catch any whales because of the higher temperatures, lack of ice, and late fall of snow. Knowing how snow and ice is formed is helpful in our own lives in case we are ever in a case where we need to live off the land.

In their reflection, this student connected the Elder visit with the reality of their community: that shifts in the climate for their local environment made it difficult to sustain Traditional practices, such as whaling.

Structured reflection assignments within the unit also worked towards having students reflect on what they were learning in relation to their lives. For example, one assignment asked students to summarize what they’ve learned in a table organized in what they already know, what they wonder, and what they learned about snow and ice in their community. In particular, a distance student from the contiguous United States self-identified as Indigenous, reflected on their interaction (Figure 5.8) with two members from his own community (e.g., not Utqiaġvik). Snow was not a regular phenomenon at their reservation, and they asked members about their limited interactions with snow. The student reflected that they knew some facts about snow and ice prior to the interview and wondered about the snow’s chemical composition. While not connecting the Traditional knowledge to Western science, the student learned about how to collect snow for drinking and how to tell if the ice was safe to walk on.

Similarly, the combination of reflective prompts on community resources influenced students’ data collection and analysis protocols, which is seen in the Chat with a Research Scientist activity (Figure 5.7b). Using the space to reflect on the information gathering assignment allowed students to consider how community member interviews related to the
project. For example, a student who self-identifies as White explains: “After talking to the elders [people at the Senior Center], I’ve learned that the top snow that is almost see-through is not the best kind to melt for consumption, and in a survival instance this is extremely helpful.” As they considered their experimental protocol with the research scientist during a verbal discussion, they mention how “they could test at different layers to measure the density since it could relate to what the person I interviewed said about drinking water.” This example reveals that students thought about community resources as they interacted with the research scientist, even if their research question was not fully inspired by the knowledge gained from community members.

5.5.3 Iteration 1 – Embodiments and Missed Connections to Tenet 1

Within this iteration, students’ research questions focused primarily on the Western science perspective even after students summarized the community knowledge from their reflection (Figure 5.7d). Continuing with the student who learned about potable water from elders at the senior center, her group discussed potential research questions and landed on “looking at density of snow from different locations around town” because it connected to earlier content in the class. When discussing as a group how they would connect samples, another student who self-identified as White mentioned:

I got an idea what we could do first for the experiment — We go, and we get a measuring cup right? Like a beaker? We go and we scoop it, and we don't compact it. And then we scrape off the top. And then we melt that snow, and we check the volume of it. So, we take the mass, and we take the volume, crystallized, and the weight and then we do the melt it and get the volume…and then we go right next to a house, and we do it one meter from the house and three meters from the house. And we just do that for two houses, one in town and one outside of town…and maybe one at the beach. And hypothesize that the snow is more moist near water…I don’t know, whatever’s good. Let's not gather the temperature. That’s too much information. Let’s just get the volume. That’s easier

While the student’s suggested protocol matched the research question, they connected to the community solely through the location of their samples in relation to density. Even when the student brought the drinking water example into the discussion during the chat with a research
**Figure 5.7.** Conjecture maps for Iteration 1, with elemental maps depicting narrative threads (a and b) and a combined map (c) that integrates both elemental maps. Results of the design that were either unintended (missed connection) or not present are represented in (d).
<table>
<thead>
<tr>
<th>Know</th>
<th>Wonder</th>
<th>Learn</th>
</tr>
</thead>
<tbody>
<tr>
<td>What did you know about snow, ice, and snow chemistry before these</td>
<td>What did you wonder about snow, ice, and snow chemistry before these</td>
<td>What did you learn about snow, ice, and snow chemistry after these</td>
</tr>
<tr>
<td>few weeks of information gathering and interviewing?</td>
<td>few weeks of information gathering and interviewing?</td>
<td>few weeks of information gathering and interviewing?</td>
</tr>
<tr>
<td>What questions has the class answered so far?</td>
<td></td>
<td>Was it everything you expected to learn?</td>
</tr>
</tbody>
</table>

My knowledge of snow and ice was much less involved before this class. I knew the basics of how snow and ice form. The basics of how they make layers, that weight affected movement and not to eat yellow snow. I knew that traction when driving on icy roads is better at -50 degrees Fahrenheit then it is at +15 degrees Fahrenheit. I had never really thought about any aspects of snow or ice beyond what I could see, before this class.

I feel like my wonderment to snow and ice are like any other subject I develop a curiosity to. If I want to know something about it, I look it into until I am satisfied or distracted. I really did not come into this class with unanswered questions about snow and ice, but the class did direct me to new questions. As we learned about more micro aspects of snow movement then what I had thought about before I did develop an interest in how chemicals concentrate in snow and ice. I feel satisfied that the questions I have been answered thus far.

One of my interviewees remembers having to help collect snow for use as drinking water. However, he was young then and only has limited memories of that time. He said he remembers that the adults were very picky about what snow to collect but he could not remember what the rules were for collection. He did say that he remembers it took a lot of snow to make enough water for the needs of his family. This same man when asked about how to tell if ice was safe to walk on said he only wondered if ice was unsafe a few times and decided that if he hurled a big rock out on the ice and it did not break through it was safe enough for him. The other person I interviewed had

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>never needed to rely on snow or ice. Both had knowledge of</td>
</tr>
<tr>
<td></td>
<td>safety for driving conditions and when not to go hunting or</td>
</tr>
<tr>
<td></td>
<td>hiking.</td>
</tr>
</tbody>
</table>

Figure 5.8. Example of student reflecting on their experiences with the research scientist.

Figure 5.9. Student example of reflection on snow chemistry unit as it relates to their life.

(1) Did you want to revise any of the following after talking with the prof: KWLS chart, research question, and experimental protocol. What changed? Why? How did you negotiate between your ideas and the prof’s comments?

I felt like our time with the prof was very beneficial. Even though I am not going to physically be there for the class field day and collect samples with the class I am trying to keep my frame of mind in a place that is preparing for this. The prof made some points that made the group think about how to maximize our time in the field. She shared that she felt it better to collect more samples then what we think we need so that when we are back in the lab we don’t regret not having collected something. We changed our collection protocol on the spot. This change was not blindly following recommendations, she made a strong point that we had just not considered.
scientist activity, they connected the topic immediately to density without its connection to survival or reasons why certain layers may be more potable than others.

Another group experienced similar disconnect between community resources and the scientific portion of the unit. The Indigenous student from the lower 48 summarized that community members mentioned where to find snow for drinking water (Figure 5.8). Still, the group chose to focus on “material that underlies the snow and how that affects ion composition in the above snow layers.” Even though this student mentioned the drinking water connection in the discussion, the group chose to relate their research question to the snow chemistry inquiry activity that walks students through the origins of inorganic ions in the Arctic snowpack. They summarized their research question to the research scientist,

*So, our thought was when we were trying to come up with places to collect snow, one of us had thought of collecting snow from right on top of the tundra versus right on top of mud and gravel. So, we were wondering how those different places would change the snow right on top of the ground? In what way? Like would there be more ions?*

The research scientist offered suggestions for the students to improve their protocol based on their research question and noted the connection to the inquiry activity. The Indigenous student from the lower 48 reflected on the experience (Figure 5.9), being appreciative of the professor’s feedback on the protocol and suggestions on how to prepare for sample collection in the harsh environment. Finally, it is important to note the absence of the community event at the end of the unit (Figure 5.7d). The primary reason the event did not occur was that the unit was implemented in the latter half of the semester, and there was insufficient time to complete all activities. We think this capstone event would have given students the opportunity to share their perspectives with members of the community and allowed space to generate productive discussions on deeper connections to their culture.

### 5.5.4 Iteration 1 – Summary and Adaptations

The student quotes in this section summarize that community member interactions often related to survival out in the tundra and subsistence activities, establishing that the embodiments of community resources and structured reflection elicited a mediating process of student reflections (Figure 5.7c). Some students connected these community resources to their data collection and analysis through the chat with a research scientist. However, in most of these
instances, students viewed interactions with the community as separate from the scientific activities in the classroom. This compartmentalization can be shown by the missed connections as they defined their research question through their focus on the Western science narrative (Figure 5.7d).

One of the major lessons from this first iteration was that we structured the unit to fit the frame of a traditional university course. It quickly became apparent that a six-week unit at the end of a full course was too constricting for the context and did not allow enough time to make explicit the connections between cultural references and academic skills in the class. For instance, we intended the Elder visit to the class to be a ‘Hook Event’ that framed the rest of the unit. When the Elder rescheduled for multiple weeks, we needed to pivot and replace the event with another activity from the unit to ensure progression in the unit. This adjustment meant we could not use classroom data as we initially intended. For the next iteration, we restructured the activities to be more modular so that the instructor could choose based on the availability of community members and the flow of the curriculum. We also intentionally spread the unit throughout the next semester to allow for unanticipated adaptations based on community events.

Secondly, the dominance of the Western science narrative appearing in students’ projects in this iteration caused us to consider how we could call attention to and focus more on sources of community and Traditional knowledge during the unit. We reflected on our position with respect to the data being collected, leading to the perspective that all design team members could be active participants in the unit sessions to surface potential connections between Traditional knowledge and Western science when students reflect on their ideas. This researcher positionality could allow for identifying the connections between worldviews and advocating for classroom space to be set aside for further discussion when merited. Within the conjecture map, this perspective led to the addition of an **Intentional Connection** Discursive Norm embodiment (grey box, Figure 5.10a), where the design team explicitly called out potential leads and connections to promote student engagement in Tenet 1 of CRE (Figure 5.7).

Finally, we recognized areas where our initial design structure limited participant engagement in the materials and took steps to promote deeper engagement. For example, we noticed that students limited their written reflections to the structure of the document we designed. The Indigenous student from the lower 48 mentioned in class that the “squares on the reflection activities were too small for what I wanted to write, and it felt weird going onto a new
We also noticed similar responses to other students’ reflections, and, as a result, we adapted most reflection activities to be verbal discussions within the lesson. This practice also aligns more closely with the verbal discourse practices of the community. To respond to the lack of community presentations at the end, we made plans to schedule a community event early in the semester.

5.5.5 Iteration 2 – Context of Iteration

We implemented the second iteration within a climate change course at Ilisagvik College in Winter 2020. This course provided an integrated overview of the science of climate change and analyzed implications of this change for communities on the North Slope of Alaska. Two distance students, neither of whom were science majors, participated in the course (Table 5.3). Student 1 self-identified as a White, non-traditional student from the lower 48 and Student 2 self-identified as an Iñupiaq, non-traditional student.

We implemented the snow chemistry unit throughout the semester to provide space for unanticipated changes. Over the semester the design team met weekly to discuss the progression of the unit and to identify ways to support implementation. For example, an Elder was not available to share their knowledge with students, resulting in the decision to use the information gathering assignment to introduce students to local and Traditional knowledge. These weekly meetings were particularly important as the COVID pandemic shifted the curriculum for this iteration. Figure 5.10 outlines the conjecture map for Tenet 1 of CRE for Iteration 2.

5.5.6 Iteration 2 – Embodiments and Their Connection to Tenet 1

The dominance of the Western science narrative in the previous iteration led us to give great emphasis to community sources of local and Traditional knowledge within this iteration (Figure 5.10a). Students engaged with community resources in multiple activities completing the information gathering assignment. This activity allowed students to explore multiple sources of local and Traditional knowledge to inform their interview with a community member of their choosing. For instance, Student 2 interviewed their mother to learn how snow and ice have changed in their lifetime. In their written reflection, Student 2 wrote:

I grew up learning, living and being taught a subsistence lifestyle of living off the land and waters… I was taught that the snow has a large part of summer harvesting. I just
didn’t remember what was taught to me. When my mom was talking about the importance of snow, I remembered what I was taught… My mom stated that when she was young, [ice] break up was loud and scary. Nowadays my mom stated that break up is not even near what it used to be. It just melts and there is no ice anywhere.

In this reflection, Student 2 described how the interview with their mother allowed them to recollect Traditional knowledge about snow and ice, and how the changing landscape influenced Traditional hunting and gathering practices in their village. This student often shared their Traditional knowledge and experiences with Student 1 and the design team. This expertise was

Figure 5.10. Conjecture maps for Iteration 2 of the snow chemistry unit. The combined conjecture map builds upon the Iteration 1 conjecture map (a). Results of the design that were either unintended (missed connection) or not present are represented in (d).
acknowledged and supported throughout the iteration, particularly in moments where Western science and Traditional knowledge converged. For example, during the chat with a research professor class session, Student 2 used their knowledge of ice cellars and permafrost thaw to describe the implications of the changing climate to Student 1 and the research scientist.

While the COVID pandemic prevented students from collecting and analyzing snow samples, students could still develop research questions and snow sampling plans based on information learned from their interviews and information gathering assignments. To encourage students to consider how Traditional knowledge could inform their research questions, design team members described intentional connections between Traditional knowledge and Western science. For instance, Student 1 mentioned how the changing climate is affecting permafrost and ice cellars in the Arctic, knowledge learned from their interview with an Elder. The design team members discussed this Traditional knowledge with Student 1 and pointed out how this knowledge could influence where they chose to collect snow samples and what data to obtain (e.g., temperature, density). Student 1 considered this connection when developing their research question and decided to focus their research question on permafrost thaw, with no mention of Western science.

Structured reflection assignments, such as the one described above, appeared to influence how students connected cultural references to academic skills and concepts. For example, after participating in the chat with a research scientist class session, students reflected on the experience, considering questions about how the research scientist’s cultural background and scientific knowledge compared and contrasted to their own. Student 1, self-identifying as White, described in their written reflection how the research scientist helped them further understand snow chemistry processes, such as the relationship between snow density and temperature. Student 1 connected this knowledge to Student 2’s cultural knowledge and experiences when they mentioned:

[Student 2’s] cultural background is worth its weight in gold! They are somewhat of an expert by virtue of the sheer fact that they have grown up on the North Slope of Alaska and have witnessed the changes with the sea ice and the snow... Summing up the class, this was an opportunity for both [Student 2] and [the research scientist] to give me feedback and insight.
We designed the chat with a research scientist activity to introduce students to an expert representing the Western science perspective, yet Student 1 found snow chemistry expertise in Student 2 as well. Student 1 mentioned how Student 2 was also “somewhat of an expert” given their experiences with the changing sea ice and snow, knowledge that then informed Student 1’s research question and snow sampling plan. The chat with a research scientist activity along with knowledge from Student 2 helped Student 1 refine their research question and snow sampling plan, though limited knowledge from the Western science perspective was represented in their final product.

During their community presentation Student 1 explained what they learned from their information gathering assignment, the snow chemistry guided inquiry activity, and the chat with a research scientist class session. Student 1 focused their presentation on their understanding of Traditional knowledge and Western science. They described these epistemologies as opposing ways of knowing that could be bridged only in specific instances (e.g., bringing Western scientists and Indigenous communities together to study a shared topic of interest). For instance, Figure 5.11a depicts a slide from Student 1’s community presentation, which shows a physical barrier between Traditional knowledge and Western science. Student 1 described Traditional knowledge as a worldview that is value-focused and passed down through generations. In contrast, Western science seeks to find the “truth” through methods of observation, prediction, and experimentation.

The epistemological divide between Traditional knowledge and Western science is...
further depicted in Figure 5.11b, where Student 1 explained how an Elder and a scientist might explore the same topic. Student 1 talked about what they learned about fast ice (i.e., ice along the coast) from their interview with an Elder, explaining how the Elder’s personal experiences with sea ice informed this knowledge. Student 1 drew upon knowledge learned from the chat with a research scientist class session and snow chemistry guided inquiry activity to explain how scientists make observations and develop methods for measuring natural phenomena. Student 1 also mentioned how the Elder “had no prior [Western science] knowledge,” but could use their Traditional knowledge to inform Western scientists about a phenomenon, a conclusion that the student reached. As in Figure 5.11a, the physical barrier between Traditional knowledge and Western science is present, with the words “Let’s Care” and pictures of flowers added, demonstrating that care and compassion could be a way to bridge these ways of knowing. It is important to note that this epistemological divide between Traditional knowledge and Western science appeared throughout the presentation and that Traditional knowledge was the primary source of knowledge for all aspects of the presentation except for the snow sampling plan.

5.5.7 Iteration 2 – Embodiments and Missed Connections to Tenet 1

Within this iteration, students’ research questions primarily originated from sources of Traditional and local knowledge, specifically interviews with community members, even after engaging with a research scientist and learning about snow chemistry processes through a snow chemistry guided inquiry activity (Figure 5.10b). While students’ research questions were developed from sources of Traditional knowledge, their snow sampling plans were primarily focused on Western science perspectives, demonstrating an epistemological disconnect between students’ research questions and their snow sampling plans. This disconnect was exacerbated when COVID pandemic restrictions limited students to potentially collecting snow samples from local sites, such as community parks. Student 2 mentioned the implications of these restrictions to the research scientist when they said:

My kids are tired of being in and we're tired of facing each other all day, every day. So, we're just trying to get out and get to different parts of [Alaska city]. And just depending on where we go, I just wanted to collect snow at those sites.

Student 2 deviated from their original research question to develop a snow sampling plan that would work for their current situation. Therefore, their snow sampling plan was primarily
focused on Western science perspectives, while their research question originated from sources of Traditional knowledge.

Another disconnect between Traditional knowledge and Western science occurred during the snow chemistry guided inquiry activity, where most of the discussion was focused on Western science perspectives. While the students did not connect many concepts from the guided inquiry activity to Traditional knowledge, they did relate some of this knowledge to their own experiences, such as describing the similarities between forest fire aerosols and sea spray aerosols. When Traditional knowledge was discussed, students often translated knowledge learned from interviews with Elders using Western science perspectives. With few connections made between Traditional knowledge and Western science, concepts from the guided inquiry activity were not incorporated into students’ research questions or their snow sampling plans. We were not expecting students to navigate between multiple epistemologies during the guided inquiry activity as it is firmly grounded within Western science perspectives. However, we did expect Western knowledge from this activity to influence students’ research questions and snow sampling plans, especially after receiving feedback on these elements from a research scientist. The lack of Western science in students’ research questions and snow sampling plans could result from the order that occurred due to the unit’s modularity. We facilitated the guided inquiry activity after students developed their research questions and snow sampling plans.

5.5.8 Iteration 2 – Summary and Adaptations

Given the dominance of the Western science narrative in the previous iteration, we prioritized space to acknowledge and emphasize the sources of local and Traditional knowledge during this iteration. Both students deeply engaged with these sources of knowledge, though this led the students to view Western science and Traditional knowledge as opposing ways of knowing. Interactions with community members, intentional connections with the design team, and structured reflection assignments led students to develop research questions focused primarily on Traditional knowledge (Figure 5.10a). The snow chemistry guided inquiry and interactions with a research scientist had little influence on students’ research questions but did inform their snow sampling plans given COVID pandemic restrictions (Figure 5.10b).

One lesson learned from this iteration was that we over-emphasized the importance of sources of local and Traditional knowledge, leading to an epistemological divide between
Traditional knowledge and Western science perspectives. We believed that the Western science narrative was explicit and persistent throughout the unit during the first iteration, so we prioritized Traditional knowledge, using intentional connections to promote student engagement in Tenet 1 of CRE (Figure 5.10a). For the third iteration, we focused on establishing a balance between Traditional knowledge and Western science perspectives, recognizing that both ways of knowing need to be acknowledged within the unit. For example, we moved the snow chemistry guided inquiry activity to earlier in the unit so students could identify connections between knowledge learned from their information gathering assignments and Western science perspectives.

Secondly, we recognized that the complexity of the unit did not provide students with a clear idea of what they were working towards. For instance, students were not entirely sure what topics they should interview community members about. To provide transparency about the unit as a whole, we presented students with an overview of the unit at the beginning of the third iteration (Figure 5.12), clearly describing what each section is and when it would occur. We also established within-unit feedback where design team members gave students formative written or verbal feedback. Recognizing the importance of community feedback, we also planned the end-
of-semester community presentations at the beginning of the semester instead of a few weeks prior, giving us more time to advertise the event.

Lastly, we attempted to find an Elder who could share their knowledge about snow, ice, and whaling with the students as a ‘Hook Event,’ but no one was available then. As the iteration progressed, we recognized that students were developing research questions focused on snow and permafrost on the tundra. Therefore, we decided to seek out a hunter for Iteration 3, recognizing that they often hold knowledge of whaling and hunting. This was particularly important as several of the provided data points were acquired from snow samples obtained from the tundra in Utqiaġvik (Figure 5.5).

5.5.9 Iteration 3 – Context of Iteration

The third iteration was implemented in the chemistry in society course at Ilisaġvik College in Fall of 2020. The course was designed for non-majors and provided examples of how chemistry relates to society. Six students, none of whom were distance, participated in the course. The students came from diverse backgrounds (Table 5.3) both in terms of culture and age—ranging from students enrolled at the local high school taking the class for college credit to older students with young families taking the class to explore career options.

Feedback from the professor and students showed that activity modularity and spreading the unit throughout the semester allowed for deeper engagement with the activities, therefore we sustained the adaptation from Iteration 2. To guide students through the unit, we implemented a road map for the project (Figure 5.12) and held a discussion to answer questions from the students about their future work. We also moved the snow chemistry guided inquiry activity to be conducted while students were working on their out-of-class interviews with community members. Students could not collect samples due to the continuation of the COVID pandemic; therefore, we followed a similar data analysis protocol for Iteration 2. We continued weekly meetings to continuously adapt material based on shifts in the COVID pandemic. Figure 5.13 outlines the conjecture map for Tenet 1 of CRE for Iteration 3.

5.5.10 Iteration 3 – Embodiments and Their Connection to T1

One focus of this iteration was to help students make more connections between Traditional Knowledge and Western Science through within-unit feedback sessions throughout
all parts of the course and making intentional connections whenever it was merited within the discussion. In particular, the feedback sessions provided a space for students to clarify their thoughts on their research questions and consider other avenues to pursue. Prior to this iteration, students brainstormed research questions as a group without intervention from the professor or graduate students. Recognizing that students were struggling to make connections between embodiments, we invited members of the design team to class for students to present their ideas and generate ways to connect between activities of the unit.

The first feedback session occurred after the Elder visit as students began considering research questions relating to their community in preparation for the chat with a research scientist. Student 3, an Iñupiaq woman with a family taking the course as a non-science major, engaged with the professor and a graduate student as they considered options:

Student 3: *My question is...how has the snow in Barrow affected the...way of life here in Barrow? This came from an [interview with an] Elder here in Barrow, Alaska.*

Professor: *So, what do you mean by “how does the snow affect the people in Barrow?”*

Student 3: *How has the snow from back then and the changes throughout the year affect how people here in Barrow live?*

Graduate Student: *So, how would you measure the snow? Like, what would you do to determine how much chloride is in the snow? Would you pick multiple locations? Would you pick multiple snow depths? Or both? Which one were you thinking about doing?*

Student 3: *Going to a location to where there would be more snow and then there were barely any snow?*

Professor: *Okay, do you have any locations in mind in Barrow where that might be?*

Student 3: *I’m in town and then like, out of town, like further out in the Tundra?*

Within this conversation, student 3 clarifies her early thoughts, considering her community member interview and how she could relate to the project. The professor asks questions to help the student think more specifically about the nature of her research question, and the graduate student helps student 3 connect to future activities within the project (e.g., guided inquiry activity and data collection). In this conversation and throughout the course, the feedback sessions generated student reflection that weaved multiple embodiments to help students consider Traditional Knowledge alongside Western Science in preparation for future activities (Figure 5.13a).
In a similar thread, making intentional connections in activities that focused on Western Science generated dialogue that promoted student reflections on their lived experiences (Figure 5.13b). For instance, student 4, an Inupiat woman taking the course to explore science careers, describes in the guided inquiry activity:

**Student 4:** Cool! The layers (Figure 5.14) — I’ve seen that before while hunting.

**Grad Student:** Can you explain more?

**Student 4:** Those...small, rounded grains are smaller than rice, but when you put your hand into it, you can move your hand around and no snow will stick to your hand unless you’re really warm. Yeah, I don’t like that kind of snow. I can’t stand it.

**Grad Student:** Why not?

**Student 4:** It hurts because it doesn’t melt when it touches you, and it’s only covered by a small layer of snow, and that’s the decomposing grains. It’s just a small layer, it’s like a crispy snow. You know, I guess that’s [what Western Science calls] the melt and freeze crust.

Seeing the different layers of snow on the guided inquiry activity reminded the student of experiences while hunting. The graduate student prompted a further response, and the student reflected on the characteristics of each layer for the other students in the course. Similarly, student 5, a high school student who self-identifies as Filipino, conveyed with his research question during the chat with the research scientist activity:

_In this experiment, I would like to study the snow on the ocean and tundra. I chose this because I wanted to know if the tundra, being a more mossy muddy environment, makes a difference on the snow’s characteristics, and what variables would contribute to those characteristics. I also want to know what ions are in the snows because of the environment. This came from the POGIL assignment [guided inquiry activity] with [the graduate student], which I found very interesting, because I never really knew that there was chloride in the snow and ocean. My two research questions are what variables from the environment would contribute to the characteristics of the snow and what ions are in these samples?_

In this passage, student 5 reflects that they initially wanted to study a general topic, such as the snow on top of different surfaces. The student cites their interactions with the graduate student for helping refine their perspective during the guided inquiry activity, connecting multiple embodiments through reflection about their research question.

The added feedback session embodiment alongside the researchers making intentional connections with both Traditional Knowledge and Western Science generated student research...
questions during the chat with a research scientist that combined multiple embodiments while affirming students’ knowledge (Figure 5.13c). For example, student 4 combined her experiences hunting and knowledge of caribou migration patterns with knowledge learned from the elder visit to construct a genuine research question:

*We would like to study this notice or study snow samples where caribou travel compared to snow in town or near the ocean. We chose this because I wanted to understand the sodium chloride concentrations in both locations. This came from the [classroom] visit with [the elder], which I found interesting because he mentioned the caribou traveled to the ocean during the spring to get more salt, which I remember from hunting.*

The research scientist, hearing this, referred to the snow chemistry guided inquiry activity and suggested that student 4 consider the ion concentration based on snow depth to see if there were trends. Based on this advice, student 4 selected samples at varying depths and produced a representation of ion concentration for her final presentation (Figure 5.15):

*So here we have a pyramid that's representing a 3D structure of the ice on the ocean, and on each level of the pyramid, you'll see a dark dashed line...that represents the chloride concentrations. And you see that they're labeled one through four. The bottom one is number one, and that is the seawater, you see the line there is the thickest, because the chloride concentrations are most abundant there. And as they travel up, they are the least concentrated at number two — as the chloride moves its way up the ice from the ocean, there's less chloride...There are chunks of scattered ice, which is number three. And in these chunks of ice, you'll find the least chloride concentrations because there's not much salt getting in there at all. And number four is the snow on the top, and there you'll have more chloride concentration because the sea spray from the ocean is spraying all over the snow.*

She then contrasted her snow sample data (Figure 5.16), with one snow sample collected over the ocean and the other over tundra, mentioning that the ion concentration of the samples over the ocean was orders of magnitude higher than that which was collected over the tundra, connecting the data to the caribou migration pattern she noticed while hunting.

### 5.5.11 Iteration 3 – Embodiments and Missed Connections to Tenet 1

While feedback sessions and shifting the Western science-oriented activities earlier in the unit helped to address the epistemological disconnect from Iteration 2, where students viewed Traditional knowledge and Western science as opposing, many students represented the worldviews without realistic connections. For instance, Student 1 (from Iteration 2), taking the course as her second science credit, recounts her research question during the community
presentation,

I wanted to study the snow samples on the tundra, for there was a large population of Arctic fox. I wanted to compare the snow [on the tundra] to the snow near the coast. I chose this because I wanted to understand the chloride concentration in both locations. I found this interesting because [the person I interviewed] talked about how he trapped more arctic fox in the past. And 10 years ago, he could get all that he wanted, and he said today it's hard to make a living as a trapper. I found this interesting because...with less snow, it's taking away their habitat, and [the foxes] don't want to be there anymore...So for somebody that's a trapper, that's been a huge impact on their life.

Student 2 initially points out two areas where they wanted to collect data (tundra vs. coast) and continued to describe a problem that she learned from her community interview without making a connection with how the chosen samples relate to the Arctic fox population. Student 5 reflects a similar disconnect, trying to relate his initial research question and what he learned from the snow chemistry guided inquiry activity to what he experienced in his everyday life,

The ocean has really taken a lot of the land and has been eroding it, and I actually lived in this part of town, and I grew up in this part of town. So, every day I would go to the beach...and when I was younger, it did not look like this. And [my partner for this project] actually lived down the road from this place, so she experienced the erosion and the damage that it has caused. Like, it has been damaging a lot of roads. And it doesn't it's also it costs a lot of money. And it's a lot of time and it's a lot of manpower....On to my research question, I chose what areas have the most chloride ions and what is the significance of the amount of chloride ions in a place that has more versus a place with a least amount of chloride ions? And I was kind of curious about this because I was thinking if chloride concentration had an effect on the rate at which permafrost melts.

While permafrost coasts have experienced a large amount of coastal erosion (Jones et al., 2020) during student 5’s lifetime, he does not relate this phenomenon to chloride concentration in the snowpack. Both students’ examples demonstrate that they were trying to connect Traditional knowledge with Western science. However, their connections did not show how the worldviews related. We posit that focusing feedback structures on connecting community resources and the data collection plan, using community feedback and scientific resources, could help students make this connection (Figure 5.13d). Also, the COVID pandemic restricting students to analyzing snow samples collected by scientists, which was unrelated (both in time and content) to the students’ research questions, could have played a role in the difficulty students faced.

232
5.5.12 Iteration 3 – Summary and Adaptations

Considering that the design team focused heavily on integrating local and Traditional knowledge during Iteration 2, we designed spaces where students could give and receive feedback on their projects. This feedback was provided by other students and members of the design team to call attention to relationships between various embodiments and the students’ research questions (Figure 5.13abc). This change led to students representing multiple perspectives from the snow chemistry project that explored questions relating to traditional knowledge (e.g., caribou migration patterns). However, many students struggled to find realistic and meaningful connections between the local, Traditional, and Western perspectives. As a result, more attention could be placed on connecting students to community and scientific resources related to the phenomenon they would like to explore (Figure 5.13d).

Recognizing that intentional connections and feedback structures helped students to represent multiple perspectives, we continue to find ways to structure these interactions to guide students to make meaningful connections between design embodiments and the perspectives represented in their projects. For instance, listening to an Elder who was a hunter affirmed student 3’s expertise on the phenomenon, which helped her choose a research question early and refine it iteratively throughout the course. However, other students did not have that opportunity because they differed culturally from the interaction (e.g., they were not Iñupiat). Thus, they could not relate to the life experience (e.g., they were not hunters), and the connection between science and the Traditional perspective was not clarified soon enough in the project for this group of students. As a result, while we still invited an Iñupiaq Elder into the classroom, we adapted the unit by including an initial research question brainstorming session after we presented the overview of the unit (Figure 5.12), found any instance to affirm the expertise that students possessed on snow and ice in their community, and supported students in learning from people in their community who were knowledgeable about the topic before moving on to other topics. In doing this, we expanded our perspective on who possessed the expertise to inform students’ projects.
<table>
<thead>
<tr>
<th>Conjecture</th>
<th>Embodiments</th>
<th>Mediating Processes</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Students can better identify with science when a curriculum is constructed that affirms their worldview</td>
<td>Tools and Resources</td>
<td>Community Resources</td>
<td>Observable Interactions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reflective Prompts</td>
<td>Video Recordings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Data Collection and Analysis</td>
<td>Chat with Research Scientist</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Community Presentation</td>
<td></td>
</tr>
<tr>
<td>Snow Chem Guided Inquiry Activity</td>
<td>Participant Structures</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Students can better identify with science when a curriculum is constructed that affirms their worldview</td>
<td>Tools and Resources</td>
<td>Community Resources</td>
<td>Observable Interactions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Task Structures</td>
<td>Video Recordings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Data Collection and Analysis</td>
<td>Participant Artifacts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant Structures</td>
<td></td>
</tr>
<tr>
<td>Snow Chem Guided Inquiry Activity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discourse Norms</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Students can better identify with science when a curriculum is constructed that affirms their worldview</td>
<td>Tools and Resources</td>
<td>Community Resources</td>
<td>Observable Interactions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reflective Prompts</td>
<td>Video Recordings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Data Collection and Analysis</td>
<td>Chat with Research Scientist</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Community Presentation</td>
<td></td>
</tr>
<tr>
<td>Snow Chem Guided Inquiry Activity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Participant Structures</td>
<td></td>
</tr>
<tr>
<td>Feedback Structures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discourse Norms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intentional Connection</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Key**

- Present
- Mixed Connection
- Not Present
Figure 5.13. Snow layering diagram from snow chem guided inquiry activity that student 4 referred to when describing her experiences with snow layers in her everyday life. Figure adapted from Domine et al., 2004.

Figure 5.14. Conjecture maps for Iteration 3, with elemental maps depicting narrative threads (a and b) as well as a combined map (c) that integrates both elemental maps. Results of the design that were either unintended (missed connection) or not present are represented in (d). Boxes in bold denote additions from a previous iteration's map.
Finally, while we successfully held a virtual meeting at the end of the unit, most participants were related to the project and not people in the community who interacted with the students. In other words, even though we planned the event early, we struggled with community member participation. While meeting virtually due to COVID was a factor, we considered having students inviting the community members they interviewed and family members to generate more diverse attendance at the final meeting.

5.6 Discussion

This manuscript tracks the design and implementation of a culturally relevant snow chemistry unit at Iḷisaġvik College in Utqiaġvik, Alaska. We used a collaborative design process (Penuel, 2020) throughout four iterations of the unit, inviting multiple stakeholders to consider how culture, context, and place can be incorporated in the classroom. To do this, we use conjecture mapping (Sandoval, 2014) to identify design considerations and adapt curricular resources based on how participants interacted with the design, asking the question: How can we use conjecture mapping to track how students engage in the tenets of CRE within the snow chemistry unit? We specifically look at how we considered students’ cultural references in their connection to academic skills and concepts (Tenet 1; Table 5.1). In this section, we discuss how

![Understanding Chloride Levels](image)

Figure 5.15. Student 4’s representation of chloride concentration as it relates to snow depth.
conjecture mapping supported systematic thinking about the collaborative design process, the limitations of conjecture mapping from our collaborative structure and study context, and considerations of the project as a whole.

5.6.1 Conjecture Mapping to Support the Design Process

To capture the inherent messiness of the design process, the project team used conjecture mapping as a way to track student interactions throughout multiple iterations, reflecting upon those interactions to make intentional adaptations to make the unit more aligned with the tenets of CRE. Our results section outlines specific adaptations that we made throughout three iterations of the snow chemistry unit based on narrative threads defined by the project team after reflection between each iteration. We combined the conjecture maps for ease of visualization in Figure 5.17, with their evolution resulting from reflection on missed connections throughout the results section (Figure 5.7d, Figure 5.10b, Figure 5.13d).

Firstly, conjecture maps helped us systematically reflect on and respond to student data related to Tenet 1 of CRE. The adaptations we made were structural, instructional, and interactional by nature. Structurally, between Iterations 1 and 2, we shifted the structure of activities to be more modular to be responsive to the uncertain timing of community members visiting the classroom so that the professor could choose amongst ways of community engagement based on available resources. The result contributed to students focusing more on Traditional knowledge in Iteration 2 when compared to Iteration 1. Between Iterations 1 and 2,
we adapted student reflection activities to be verbal after student feedback on the quality of responses with written prompts from the initial design. This shift resulted in more detailed student responses to reflective questions, where we could follow up and learn more about the students’ lived experiences outside the classroom. This shift also led us to make interactional adaptations centered on how we, as a design team, interacted with participants throughout the study. For instance, establishing a discourse norm of intentional connection allowed students to make a more salient connection between Traditional knowledge and Western science during Iterations 2 and 3. This norm, in combination with adding feedback structures as an instructional component after Iteration 2, affected which embodiments connected students’ cultural references to academic skills and concepts. The evolution throughout three iterations is depicted in Figure 5.17.

Secondly, it is important to note that conjecture maps allowed researchers to identify narrative threads to focus on intentional adaptations within greater geographical and societal contexts. Because we collaboratively identified design embodiments while conceptualizing students’ interactions with the identified embodiments early in the design process, we could intentionally consider how we as team interacted with the design throughout implementation. This consideration helped us overcome a 3000-mile geographical barrier by focusing attention on specific parts of the project when time was limited. For instance, Iḷisaġvik often held classes in the evening (Alaska time) to accommodate students’ work schedules. Because of this, data collection and researcher interactions often extended late into the evening (e.g., from 10 pm-1 am local time). Previously identified narrative threads from the conjecture maps and reflections provided the design team with specific focal points to collect data to lessen the effect of the fatigue due to the time difference. These narrative threads also helped structure our limited virtual collaboration time around specific embodiments and intended outcomes.

Also, the COVID pandemic occurred during Iterations 2 and 3, posing a tremendous barrier to embodiments that relied on in-person interactions. For example, students could not collect snow samples due to social isolation guidelines, which likely influenced their research questions, data analysis processes, and connections to their community. Conjecture mapping provided a framework for the project team to structure collaboration around the adaptation of embodiments to provide students with a similar experience in light of restrictions due to the pandemic.
Figure 5.17. A compilation of all conjecture maps, from Iteration 1 (a), Iteration 2 (b), and Iteration (c) depicting an increased connection between embodiments and outcomes as we reflected on mediating processes from within each iteration.
Thirdly, conjecture mapping helped the design team reflect on specific structural shifts throughout the implementation while affirming student experiences, backgrounds, and abilities. For instance, when students focused heavily on the Western science knowledge in their projects with Iteration 1, conjecture mapping helped us identify and shift the unit's structure to emphasize community interaction. Thus, when students chose research questions unrelated to Western science in Iteration 2, the project team discussed how we could make intentional connections to guide students throughout their project. These actions helped the project team take responsibility for student outcomes, affirming students’ experiences and avoiding deficit orientation throughout the implementation process.

5.6.2 Limitations of Conjecture Mapping and Suggestions for Future Research

While conjecture mapping throughout the design and implementation process was beneficial, we found several limitations to the analysis technique. We noticed that the conjecture maps naturally became more complicated as iterations progressed. As we reflected on the maps between iterations, we adapted missed connections between embodiments and mediating processes, so they aligned more with the outcome. This shift caused more embodiments, as well as connections between embodiments and mediating processes, to be displayed on the maps as iterations progressed (Figure 5.17). As a result, there appears to be a potential limit on the number of iterations that can be mapped in a design before complexity renders the conjecture map too complex to structure productive reflection and adaptation.

We also found that using conjecture maps that contained multiple outcomes across multiple iterations made the maps too complex to process without making intentional decisions to narrow the focus of the design team’s structured reflections. Other analyses with multiple conjectures also ran into similar problems (Wilkerson, 2017), making it important to consider grain size when conceptualizing design using conjecture maps. In another study, Lee et al. (2022) suggest a second, equity-oriented conjecture to inform the overarching design. We agree that this would allow for a reflective structure where the designer makes intentional choices to mitigate power imbalances to promote equity, both from the design team and classroom structures. However, we think adding another conjecture would increase the complexity of the visualization, rendering the tool difficult to use when the implementation involves multiple iterations. Instead, we suggest considering an equity outcome, alongside other proposed
outcomes, to inform the design of equitable practices from within design embodiments to promote equitable structures. With this suggestion, the designer could determine which embodiments promote equitable outcomes, design outcomes, or both, and suggest adaptations based on each outcome.

The complexity of the conjecture maps limited the extent that we reported the data. In this project, we analyzed implementation data looking for students' connections to the four tenets of cultural relevance. However, we made the intentional decision to limit the results and discussion here to the first tenant due to space constraints, introducing a level of bias. The project team had salient discussions around Critique of Discourses of Power (Tenet 4, Table 5.1), from immediate and greater cultural perspectives (e.g., Western science and Traditional knowledge, settler-colonial narratives, and structural inequity), and decided that Tenet 1 provided the most complete example for how conjecture maps were used to inform adaptation. Including multiple project stakeholders in the process of helping us make sense of the data and identifying which narrative threads to report helped limit this bias. To do this, before finalizing our conjecture maps, the project team held conversations around which threads, as identified by the researchers, aligned with the experiences of the other project team members.

How we used conjecture maps centered the researchers in making course-altering decisions during the reflection process. While many people collaborated on the conjecture maps throughout implementation, the researchers identified and promoted specific narrative threads as important considerations. While the project team eventually reached consensus on which tasks to focus adaptation, the researchers’ familiarity with the data was a source of power, influencing the design process to focus on activities that the researchers thought would meet a specific outcome (e.g., Tenet 1). We identified this power imbalance after we completed the implementation of the project. We recommend including multiple stakeholders in the process of identifying focal points for adaptation that could promote epistemological diversity and break down this power inherent power imbalance.

This implication leads to the question: for whom do we make conjecture maps and how do we include these stakeholders in the decision-making process? We conceptualized conjecture maps similar to Hoda-Wilkerson (2017), using them as devices to structure reflections amongst the design team. Lee et al. (2022) proposed using conjecture maps with participants to determine how they conceptualize equity from within their classroom. The idea of using conjecture maps
for participants outside the design team was proposed after we built our framework for this project. However, we agree that including participants in structured reflection around the conjecture maps could be a promising way to distribute and track decision-making across the design team and stakeholders throughout adaptation.

5.6.3 Conclusions

While the project produced several examples of students integrating Traditional knowledge with Western science, it is important to recognize that many struggled with connecting the two worldviews. For instance, students either approached their project wholly from a Western perspective. This was depicted in Iteration 1, where students focused on the density of snow, or they explored Traditional knowledge but could not connect their ideas to the Western science, and in Iteration 3, where students focused on permafrost and coastal erosion but could not connect their ideas to inorganic ions in the snowpack.

We propose two reasons for the resiliency of this disconnect throughout the project. Firstly, while we intended to leverage and affirm sources of Indigenous knowledge-construction alongside the epistemic practices of science, we recognize that the process of designing a research project to explore a phenomenon privileges the Western perspective of science. As we reflected on student interactions with the embodiments throughout the project, we realized that the tools we gave students to explore snow and ice around their community originated from research practices from prior experiences of the design team (e.g., the Mohr method). Limiting students’ exploration of snow and ice to physical properties helped us appreciate snow morphology’s relative complexity and limitations in answering student-led research questions that required a broader expertise of multiple realms of science. During Iteration 4, we gave students the flexibility to pursue research questions that were pertinent to their context, requiring us to consider a broader scope of scientific resources to complement their projects. Considering the prevalence of the Western science perspective, we quickly realized that the identities of the project team limited our cultural perspectives to approaching science. For instance, while we intended to affirm Iñupiaq perspectives of science, we learned that this perspective needed clarification and not all members of the design team was not positioned to make claims of this nature as outsiders to Iñupiaq culture. We accepted this inherent limitation and promoted Iñupiaq
efforts to define and clarify their perspective of science in relation to the Western perspective (Erickson, 2020) to inform future work in their community.

Secondly, it is important to name that collaborative design holds in tension the expectations of many parties, with the eventual product containing a blend of these expectations—while the researchers may desire a specific outcome (e.g., affirming Indigenous perspectives alongside Western Science), the contexts and identities of the design team are important factors when considering the final outcome. For instance, the Iḷisaġvik professor’s role is to prepare students for future college-level science work. Throughout the project, she consistently reminded the researchers that our snow chemistry unit was taught alongside content objectives that were Western science specific, potentially influencing how students approached the project. Also, partnering with a scientific researcher naturally caused the project to focus on Western science analysis techniques to answer students’ research questions. These identities, in combination with the students’ prior experiences with science (i.e., secondary classrooms focused on Western science perspectives), contributed to a nuanced outcome even when the design process explicitly focused on integrating multiple perspectives.

Finally, we believe that tracking collaborative design using conjecture mapping helped the design team identify the (otherwise latent) tension of backgrounds, identities, and expectations throughout the design process. This process enabled us to structure reflection to inform adaptations that affected students’ connections between cultural references and academic skills and concepts (Figure 5.17) by affirming the resources that all stakeholders brought to the project. While the process can certainly be improved, especially considering the diversity of epistemologies represented in the design process, conjecture mapping allowed us to track and report our initial design, adaptations during implementation, and our reasoning behind these adaptations. In this, we conclude that providing a sober analysis on how we achieved the intended outcomes was as important as the outcomes themselves, especially when collaborating within diverse perspectives to consider cultural relevance in the classroom.

5.7 Acknowledgements

We would like to thank the community of Utqiaġvik for their warm hospitality and willingness to engage in a partnership. In particular, we thank the community members who were interviewed by students and Elders who visited the classrooms during the project. We also
thank the students who participated and individuals who offered us their knowledge of snow, ice, culture, and community. Also, we are grateful to Ilisaġvik College and Ukpeagvik Iñupiat Corporation for hosting and guiding us as we visited. We acknowledge Prof. Barry Fishman, Prof. Vilma Mesa, Prof. Anne Gere, Leah Bricker, our advisory board, Prof. Katy Hosbein, Ina Zaimi, and J.J. Mayers for their intellectual contributions to the project. We thank the National Science Foundation for funding the project (Award Number: 1821884).

5.8 References


Chapter 6
Reflective Memo – A Delicate Dance

My work contributes to the greater picture of education research focusing on the collaborative design of curricular materials to promote justice-oriented outcomes for students in classrooms at all levels. It explores multiple layers to the question, “For whom do we design?” calling into question the researcher-centric design practices of discipline-based education research through the inclusion of diverse stakeholders at the design table. To do this, I describe a multi-year collaboration between two drastically different institutions in terms of culture, resources, and ecological climate to design a snow chemistry unit where students study the changing environment in a way that affirms Iñupiaq and Western science perspectives. My work clarifies what Western Science and Engineering Practices mean and how they relate to CRE. It also provides an example of the negotiation process between practitioners’ critical knowledge and designers’ critical components, as the design is adapted through multiple iterations of implementation. Through systematically tracking the collaborative design process, designers can promote reflective structures that encourage intentional adaptations towards design outcomes, affirm resources embedded within cultures, and overcome geographical and societal barriers. By doing this, designers can encourage students’ engagement in multiple perspectives of science, focus classroom activities on issues that are important for their communities, and affirm the inherent strength of their cultures. I conclude with a reflective memo to summarize contextual factors in the greater research project, their relation to reform efforts that informed the project, and key learnings as a result of the research presented in the dissertation.

6.1 Positions of Power

The subject of this dissertation was the product of multiple stakeholders’ efforts across diverse settings that included cultural, institutional, and professional differences among contributors. As a result, power imbalances, both latent and explicit, greatly affected the outcome of the project even though they were not represented within the report. Within this chapter, I
define power as an agent that determines peoples’ participation within a greater structure. Power can manifest among individuals that possess differences that affect their roles and participation in a structure. For example, when an individual feels unable to speak up at a meeting because of tenure differences between colleagues. Power can also be considered as individuals interacting with greater structures that affect their outcomes, such as when individuals from a specific demographic are systematically affected due to the characteristics of their demographic, such as when Indigenous students are forced to learn Western-centric versions of history. In either case, power affects the outcomes of individuals, their agency within greater structures, their ability to form a self-identity, and ultimately, whose values are promoted within designs (Brayboy, 2005; Costanza-Chock, 2018; Esmonde & Booker, 2016; Gutierrez, 2002; Herrenkohl et al., 2018). From within the context of the collaborative design project, I will consider examples of the power dynamics between various stakeholders – greater reform efforts and the designers, the community and the designers, the designers themselves, and the practitioner with the rest of the design team – and ways in which these dynamics affected the course of the project.

6.1.1 Power between Reform Efforts and Designers

Throughout the project, greater reform efforts informed the design and implementation of the snow chemistry unit. Explicitly, we aligned ourselves with efforts to embody science practices (National Research Council, 2012) through research projects (Corwin, Graham, & Dolan, 2015) that relate classroom content to students’ communities (Aronson & Laughter, 2016). By doing this, we intended to place students as active participants in the science learning process, where students would learn science by doing science, as is depicted by the Science and Engineering Practices (National Research Council, 2012). Initially, we did not question the perspective of the practices themselves, resulting in the unintentional centering of the Western perspective by consulting reform efforts that defined science from a singular, Western worldview. Reflecting on how students produced research projects that centered Western perspectives amidst Traditional knowledge structures, the education research team began recognizing the innate and latent power associated with the term science from within reform documents. For instance, even though we designed activities that brought Traditional perspectives into the classroom alongside Western science, the very task of designing a research project latently promoted a Western perspective, falsely defining a “correct” process that
students should use to explore snow and ice in their community. Especially within a space where multiple cultures intersect, researchers who engage in collaborative design should intentionally question the perspective of the reform efforts that guide their research to ensure alignment with the cultural perspectives of the communities they serve.

6.1.2 Power between the Community and Designers

In many ways, our team sought to refute the perspective that visiting scientists come, gather data, and leave without interaction from the community, recognizing that the very act of researching can promote colonist perspectives (Tuck & Yang, 2014). To address this imbalance, we hosted community meetings, invited community members into the classroom, and consulted with community members throughout the project, which was beneficial to both students and the design team for different reasons. Students could extend learning beyond the boundaries of what we considered to be valid (and classroom-based) sources of knowledge, including resources that they considered important in their own learning process. The design team learned how climate change was affecting the community of Utqiagvik and characteristics of another perspective of science that was different than what the reform efforts were promoting. While more could have been done to include community members in the project, we became more proficient as we gained experience and connections in the community during our visits.

However, there existed a deeper reflection concerning designer interactions within the community. Early in the project, the education research team conducted interviews with community members to learn about their perspectives of science to guide our design. One particular interview characterized this deeper tension:

*Why do I need to learn your science? What would I do with it? In our community, when we learn something from the outside, we always bring it back. Let’s say: if I were to go out and become an aerospace engineer, which is the goal of many of your [NSF researcher’s] projects, what would I do with it? Where would I use that knowledge here in Barrow? [Researcher Memo Following a Community Member Interview, 2019]*

This comment haunted me throughout the course of the project, leading to questions about the utility of the subject we were promoting. To this point, I always assumed that Western science could be used to promote greater forces in democracy – creating pathways for people to improve their social and financial status, to spur innovation and productivity for the greater good of
society – and yet, my assumption was openly challenged by an authentic and contextualized perspective in a way that will likely remain unresolved throughout my career.

Ultimately, the power dynamic between designers and community members rests in the values that are promoted within the designs themselves. Since our design and implementation were informed by reform efforts that latently promoted Western perspectives, our interactions with the community were laced with colonist ideals that deserved disentangling. We started this process later in the project, openly asking questions such as: what is Iñupiaq Science? why do we need to teach Western perspectives of science to these students? what is the point of the project? to create scientists? to give students salient examples of science so that they can be informed citizens? what is our role in relation to this community’s science-learning infrastructure? At the heart of collaborative design is a recognition of whose values we are promoting and the utility of those values to the communities in which we design. For the design team, it means effort should be made to identify members of the community who can clarify these questions and inviting these community members to the design table. Realizing the goal of a decolonized curriculum requires the consistent inclusion of such diverse perspectives at every stage of the design and implementation process while recognizing that our research agenda is often peripheral to these individuals’ everyday lives.

6.1.3 Power among Design Team Members

Design team member identities affected both the outcome and process of the design itself. Concerning the Western-centric nature of the student interactions with the design, it is important to disclose the positionality of the designers themselves: all members of the design team identified with Western cultures, possessed limited levels of experience with Iñupiaq culture, and were formally trained in Western perspectives of science. Throughout the course of the project, even though the design team invited community members to promote Iñupiaq perspectives and spent extensive time and effort learning about the culture that we sought to promote, our positionality as outsiders limited the extent to which we could construct learning environments that promote perspectives outside of the Western model of science. With this in mind, I emphasize the aforementioned point: diversifying the perspectives of science represented in the classroom requires the active and continuous participation of individuals who possess expertise of non-Western perspectives in the design process.
Within the Western perspective of the design team, there existed power dynamics that privileged certain perspectives above others. For instance, individuals who possessed expertise in Western-scientific processes (e.g., research scientists) carried greater power over other forms of expertise in the design process. For example, the existence of a chat with research scientist activity, without elevating individuals who possessed expertise in localized and Traditional knowledge to the same level, explicitly centered Western science as students conceptualized their research projects. In this activity, students received feedback on their research questions and experimental protocol from a Western scientist with the latent assumption that their protocols would change based on this feedback without recognition of and spaces to affirm students’ expertise from living in the Arctic. While we adapted to create these spaces through intentional connections (e.g., education researchers asking students to expand upon expertise when it was noticed throughout the course) and feedback structures (e.g., leading early brainstorming sessions, where students considered research questions based on their community interactions with education researchers to affirm other forms of expertise), these did not have the same effect as inviting a member of the community to provide feedback at the same level as a Western research scientist.

Latently, there was a delineation of power between individuals who possessed Western science expertise and individuals who possessed other forms of expertise from within the design team. In particular, considerations surrounding positionality, expertise, and culture that were suggested by members of the design team who possessed other forms of expertise were met with resistance throughout the design process. On the procedural level, this resulted in reflective memos and data analysis that were limited to specific members of the design team, missing opportunities for documenting the effects of the project on the perspectives of the design team, such as how the community of Utqiaġvik influenced all design team members’ perspectives of science.

As a result of these power dynamics within the design team, I made the intentional decision to avoid discussion surrounding the fourth tenet of Culturally Relevant Education (e.g., critiquing discourses of power) even though I consider it the most important for equity and justice work. In early iterations, the education research team considered the fourth tenet throughout analysis but found limited examples where students questioned power structures when prompted. Reflecting on this, I realized students’ responses were likely linked to the
unreconciled power imbalances within the design team. Discussing this with the education research team, we recognized that it could be an unreasonable expectation for students moving forward within the structure of design. In other words: if the design team did not actively critique our own discourses of power, how could we expect students to do it in the classroom?

To facilitate collaboration centered around issues of equity and justice, design teams need to build structures to question their own power dynamics if they want to address power imbalances in the classroom. Learning from these experiences, it is important to recognize the necessity of a norming process for the design team, building structures that make explicit the expertise of each individual (e.g., not just the PIs on the grant), clarify how design and adaptation should occur throughout the project, consider how conflicts are handled within the design team, and reflect on limitations of the identities of the design team itself. These norms should also be revisited regularly throughout the lifetime of a partnership.

6.1.4 Power between the Practitioner and the Rest of the Design Team

Since we engaged in collaborative design, we deliberately included the practitioner as a member of the design team. This positioning was due to the findings in Chapter 2, recognizing the importance of learning about and affirming a practitioner’s critical knowledge while constructing spaces of negotiation where practitioners and designers collaborate to adapt for context and preserve the critical components of a design. However, the practitioner’s position as the sole member of the design team who lived in Utqiaġvik, interacted with the students in an instructional capacity, and possessed no affiliation with UM, introduced a complex power dynamic that merited a separate section. As the practitioner was responsible for the content in their course and their students, they regularly reminded the design team that our design goals were peripheral to the content they needed to cover, which was healthy for the ethos of the project.

As we designed and implemented, we made many considerations based on the practitioner, who graciously invited us into their classroom. We needed to build a curriculum that worked sustainably from within the practitioner’s context, and to do this, we needed to navigate the power related to transfer of materials into classrooms with fidelity to the designers’ expectations. The practitioner possessed prior experience in CRE, designing activities that bridged traditional knowledge and western science for her biology students. Also in
consideration was the goal to design a unit that worked for the practitioner, their students, and their context, so we observed their classroom and asked questions on their thoughts on teaching and learning. The education research team recognized that our specialization in education could be held in power over the practitioner, so we made it a point to take a non-evaluative stance as we interacted with their classroom. When the practitioner vocalized discomfort with the materials that were initially designed, we pivoted to lead instructional activities to model the lessons we wanted them to implement. We also took advantage of any opportunity to engage with the practitioner in a non-education fashion, which involved meals together and late nights playing Yahtzee with our practitioner’s community. Collaborative design necessitates the prioritization the practitioner’s voice, expertise, and humanity, partnering with them from within their specific context to enact change.

Considering the power dynamics between the practitioner and the design team demonstrates the perspectives of CRE for many people within Western science paradigms (including many discipline-based education researchers). Prior to this project, examples of CRE within discipline-based education research focused primarily on the first tenet—connecting cultural references and academic skills and concepts. Within this partnership, the practitioner led students through examples of this first tenet, spending years to perfect this from within the context of their classroom. We certainly drew upon this knowledge throughout the course of the project. However, when the practitioner expressed hesitation towards activities that focused on the other tenets of CRE, individuals who approached CRE from the Western science perspective did not see utility in the other three tenets, which led to the unit being underdeveloped in critical reflection, cultural competence, and critique of discourses of power. It also reflects that the other three tenets require years of partnership with a willing and reflective practitioner to successfully explore, design, and implement. Reflecting on these interactions reinforce the need to clarify norms early in the collaborative design process, affirming the multiple perspectives of expertise present within the design team and building structures to communicate whether we are asking too much of the practitioner.

Within this dynamic, it is important to note the interplay of expectations between what we intended on accomplishing as an education research team and the reality of the classroom context where our design took place. It was noted throughout multiple chapters that the reflective structures in the unit shifted from written to verbal based on student and practitioner data.
Initially, the education research team included writing prompts, structures for feedback, and peer revision in the design. We thought it was important that students develop as communicators no matter their professional outcome. However, as the design transferred to practice, it became clear that the structures we developed to reinforce writing deviated greatly from the practices of the practitioner, with many of our structures remaining unused throughout the course of the collaboration. We adapted to a verbal structure so that we could capture student thinking to support the goals of the project. While this adaptation did not serve students’ continued growth as writers, the verbal reflection seemed to better align with the narrative style of the Iñupiaq community. The power dynamic of the design team led us to heavily adapt our reflective structures to preserve rapport within the design team and collect data surrounding the research goals of the project. Considering this within collaborative design, involving people in the adaptation process who were knowledgeable about writing could have helped us determine appropriate verbal and written reflective structures. However, it is important to recognize that the practitioner is professionally responsible for the outcome of the students, and therefore our role as researchers and the activities we select should be considered with this in mind.

6.2 Concluding Remarks

While presenting on this dissertation, committee member Prof. Brian Coppola asked: Where can we draw the line? What expectations should we have concerning our participants in relation to what is required by reform efforts to shift instruction to embody the practices of Western scientists (amongst others)? It is clear that he has deeply considered this question during the era of promotion of practice-based science education (Coppola, 2016), and the relationship between teacher experiences with Western science and the expectations reform efforts place on teachers to embody the practices of Western scientists. As a teacher-turned-researcher-turned-designer during the rollout of the Next Generation Science Standards and a global pandemic, I appreciate the rhetorical nature of his questioning—the discourse it invites should be centered in a wide array of fields intersecting with science, education, and design. This discourse is unequivocally linked to the positioning of my research in the first chapter: while we have certainly set a high bar for science education in this country, the consequences of the alternative are devastating to a diversifying society that is questioning expertise. Our reform of the vision should expand to include the reformation of the methods we employ to train teachers, design
curricula, and support instruction. The emphasis should not focus on teachers’ lack of expertise, but education research’s need to build and promote infrastructures that align teachers with and support implementation of their vision for science education. Society depends on it.

Collaborative design constructs a pathway to explore the line between research and practice by bringing diverse stakeholders to the design table and distributing expertise so that the vision of justice-oriented, practice-based science education can move towards reality. The process involves a delicate dance that holds in tension the power dynamics between reform efforts, designers, participants, and communities to construct classroom materials that embody the value sets of reform efforts, designers, participants, and communities. The dance is delicate, where focusing too much attention on any one stakeholder could result in the propagation of power imbalances that collaborative design seeks to address. Diversification of the stakeholders at the design table also provides the support necessary for practitioners to consider issues of culture and authentic disciplinary engagement from within their own classroom as they adapt materials for their context. My work continues to clarify how collaborative design takes place, showing how the disruption of power dynamics amongst researcher-designer, participant-instructor, and student-community can lead to an equitable design process that benefits all stakeholders.

6.3 References


